Progress Report on the Global Data Processing System, 2002
United Kingdom
Met Office (Bracknell)

1. Summary of highlights

1.1 Forecast models

A major upgrade to the Met Office Unified Model (UM) was implemented on 7th August 2002 (Bell *et al.* 2002). The package of changes was under trial for over a year and is known as “New Dynamics” (UM 5). This change was the biggest seen in the Unified Model for at least 10 years.

In the pre-operational trial of the “New Dynamics” model, which lasted almost a year, tropical cyclone track forecast mean errors were reduced by 5.4%. Track forecast skill scores against climatology and persistence were increased by 6–8%. The model's tendency to weaken tropical cyclones erroneously was eradicated and intensity tendency skill scores were increased by an average 15%.

The shelf-seas model was upgraded to use a hybrid vertical co-ordinate to improve representation of the surface layers in deeper water. The new model uses a Mellor Yamada turbulent-mixing scheme. The forecast area was increased to cover 40ºN to 65ºN, 20ºW to 13ºE, and boundary conditions are taken from the deep ocean Atlantic FOAM model. The revised model, known as the Atlantic Margin model, uses the latest POLCOMS formulation.

The shelf seas model was upgraded to the "Atlantic Margin" model.

The main changes to the Nimrod system during 2002 were:

12th February	A severe convective weather forecast was introduced, concentrating on severe thunderstorms, large hail and tornadoes
24th June	Allowance for the reduction in visibility due to precipitation was introduced into the visibility forecast
9th August	Nimrod was altered to deal with the introduction of UM5
12th September	Processing of 1-km resolution radar data was introduced
26th September	An improved version of the GANDOLF rainfall forecast was introduced
17th December	The European version of Nimrod was introduced

On 2nd December 2002 the preliminary global model (PGM) run was removed and merged with the main global model run. This ensures consistency of NWP output. It made valuable computing space to allow further enhancement of the NWP suite and the introduction of new numerical models in the future.

1.2 Observations, quality control and assimilation

The mesoscale data assimilation system was upgraded to include the following.

7th August	The version of the assimilation scheme prepared to accompany the new model was introduced along with the model. Changes to accommodate adoption of the new dynamical formulation of the mesoscale model.
4th December	A new set of forecast error covariances was implemented, and the nudging coefficient for cloud data was reduced. The coverage of the UK weather radar network was extended by a further set of 6 French radars. New background error covariances, based on a longer and more appropriate sample. Re-tuning of MOPS-retrieved cloud data, giving less weight to observations.

The following data assimilation upgrades were made to the global model.

7th August	Changes to accommodate adoption of the new dynamical formulation of the global model.
1st October	Commencement of assimilation of ATOVS data from NOAA-17.
2nd December	Replace uninitialised analysis scheme with initialisation using digital filtering of increments in which a Perturbation Forecast model is integrated forwards and backwards over the period of data ingestion. This replaces the gradual introduction of increments through the Incremental Analysis Update (Bloom *et al*. 1996) scheme by an insertion directly at T+0.
10th December	Commence assimilation of Seawinds scatterometer data from the Quikscat satellite to retrieve surface winds. Replace SATOB-format winds from Meteosat by BUFR-format.

2. Equipment in use at the centre

2.1 Centralised mainframe systems

A) Front-end mainframe computers	B) Supercomputers

2.1.1 Make and model of computer

A) IBM 9672 – R45 IBM 9672 – R35	B) Cray T3Ea (880 PEs) Cray T3Eb (640 PEs) (PE – processor element)

2.1.2 Main storage

A) 2 Gbytes (R45) 1.5 Gbyte (R35)	B) 128 Mb per PE (T3Ea) 256 Mb per PE (T3Eb) (16 PEs on each system have 512 Mb)

2.1.3 Operating system

A) OS/390 Version 2, Release 9	B) UNICOS/mk 2.0.5

2.1.4 External input/output devices

A) 1 Terabyte of online disk storage LAN attached desktop PCs, work-	B) 1440 Gbytes (T3Ea) 1920 Gbytes (T3Eb)

stations and printers

2 line printers

32 magnetic cartridge drives connected to a GRAU automated tape library system with a capacity of 28,000 cartridges.

18 StorageTek 9840 cartridge drives connected to a StorageTek Powderhorn tape library with a capacity of 5700 cartridge slots.

FileTek StorHouse data server (MASS)
Sun E6500 UltraSPARC processor and 16 StorageTek 9840 cartridge drives connected to a StorageTek Powderhorn tape library with a capacity of 5700 cartridge slots giving a total volume storage of 78 Tb.

2.2 Desktop systems for forecasters

The Hewlett-Packard UNIX-based workstation known as “Horace” (anon. 1999; Radford 2000) continues to be used at the Met Office’s main forecast centres in Bracknell and High Wycombe. It is used increasingly by other meteorological organisations throughout the world as their visualisation and production system.

A PC-based production system known as “Nimbus” is used by the Met Office at all its subsidiary forecasting offices such as the civil centres and military bases. Nimbus uses Microsoft NT as its operating system. Many “off the shelf” software packages are used within Nimbus, with the meteorological visualisation written in house using Delphi. All the Nimbus sites are connected to each other and to Bracknell using X400 messaging communications and a TCP/IP wide area network allowing interactive communications between sites and Bracknell.

3. Data and products from GTS in use

3.1 Observations

The global data assimilation system makes use of the following observation types. The counts are averages for October, excluding newer data types or formats received but not yet processed for assimilation.

Observation group	**Observation Sub-group**	**Items used**	**Daily extracted**	**% used in assimilation**
Ground-based vertical profiles	TEMP	T, V, RH processed to model layer average	1,200	97
	PILOT	As TEMP, but V only	900	90
	PROFILER	As TEMP, but V only	3,200	75
Satellite-based vertical profiles	ATOVS	Radiances directly assimilated with channel selection dependent on surface instrument and cloudiness	2,000,000	3
Aircraft	*Manual* AIREPS	T, V as reported with duplicate checking and blacklist	25,000	21
	Automated ACARS/AMDAR /ASDAR		120,000	60
Satellite atmospheric motion vectors (SATOB code)	GOES 8, 10	High resolution IR winds	140,000	10
	Meteosat 5, 7	IR, VIS and WV winds	9,000	98
	GMS 5	IR, VIS and WV winds	7,000	92
Satellite-based surface winds	SSMI-13,15	In-house 1DVAR wind-speed retrieval (no moisture yet)	3,000,000	1
Ground-based surface	Land SYNOP	Pressure only (processed to model surface)	30,000	80
	SHIP	Pressure and wind	6,000	90, 95
	BUOY	Pressure	9,500	75

3.2 Gridded products

Products from WMC Washington are used as a backup in the event of a system failure (see section 7.2.3). The WAFS Thinned GRIB products at an effective resolution of 140 km (1.25° x 1.25° at the equator) are received over cable in 6-hour intervals out to T+72. Since October 1996 we have also been receiving products over the ISCS satellite link. Fields in this format include geopotential height, temperature, relative humidity, horizontal and vertical components of wind on most standard pressure levels, rainfall, mean sea-level pressure and absolute vorticity.
Products received from MétéoFrance, Deutscher Wetterdienst and ECMWF (including Ensemble Prediction System forecasts) are used internally for national forecasting.

4. Data input system

Fully automated.

5. Quality control system

5.1 Quality control of data prior to transmission on the GTS

Automatic checks are performed in real time for surface and upper-air data from the

UK, Ireland, Netherlands, Greenland and Iceland. Checks are made for missing or late bulletins or observations and incorrect telecommunications format. Obvious errors in an Abbreviated Heading Line are corrected before transmission onto the GTS.

5.2 Quality control of data prior to use in numerical weather prediction

All conventional observations (aircraft, surface, radiosonde and also atmospheric motion winds) used in NWP pass through the following quality control steps:

1) Checks on the code format. These include identification of unintelligible code, and checks to ensure that the identifier, latitude, longitude and observation time all take possible values.
2) Checks for internal consistency. These include checks for impossible wind directions, excessive wind speeds, excessive wind shear (TEMP/PILOT), a hydrostatic check (TEMP), identification of inconsistency between different parts of the report (TEMP/PILOT), and a land/sea check (marine reports).
3) Checks on temporal consistency on observations from one source. These include identification of inconsistency between pressure and pressure tendency (surface reports), and a movement check (SHIP/DRIFTER).
4) Checks against the model background values. The background is a T+6 forecast in the case of the global model and a T+3 forecast in the case of the regional or mesoscale model. The check takes into account an assumed observation error, which may vary according to the source of the observation, and an assumed background error, which is redefined every six hours using a formulation that includes a synoptic-dependent component.
5) Buddy checks. Checks are performed sequentially between pairs of neighbouring observations.

Failure at step 1 is fatal, and the report will not be used. The results of all the remaining checks are combined using Bayesian probability methods (Lorenc and Hammon 1988). Observations are assumed to have either normal (Gaussian) errors, or gross errors. The probability of gross error is updated at each step of the quality control, and where the final probability exceeds 50 per cent the observation is flagged and excluded from use in the data assimilation.

Special quality control measures are used for satellite data according to the known characteristics of the instruments. For instance, ATOVS radiance quality control includes a cloud and rain check using information from some channels to assess the validity of other channels (English *et al.* 2000).

6. Monitoring of the observing system

Non-real-time monitoring of the global observing system includes:

- Automatic checking of missing and late bulletins.
- Annual monitoring checks of the transmission and reception of global data under WMO data-monitoring arrangements.
- Monitoring of the quality of marine surface data as lead centre designated by CBS. This includes the provision of monthly and near-real-time reports to national focal points, and 6-monthly reports to WMO (available on request from the Met Office, Bracknell).
- Monthly monitoring of the quality of other data types and the provision of reports to other lead centres or national focal points. This monitoring feeds back into the data assimilation by way of revisions to reject list or bias correction.

Within the NWP system, monitoring of the global observing system includes:

- Generating data coverage maps from each model run (available on the Web).

- A real-time monitoring capability that provides timeseries of observation counts, reject counts and mean/root-mean-square departures of observation from model background. Departures from the norm are highlighted to trigger more detailed analysis and action as required.
- Monitoring of satellite observations includes timeseries of comparisons of observations versus model background for separate channels plus comparisons of retrieved fields versus model background for different model levels.

7. Forecasting system

The forecasting system consists of:

1) Global atmospheric data assimilation system (3DVAR)
2) Global atmospheric forecast model
3) Mesoscale atmospheric data assimilation system (3DVAR)
4) Mesoscale atmospheric forecast model
5) Stratospheric global atmospheric data assimilation system (3DVAR)
6) Stratospheric global atmospheric forecast model
7) Transport and dispersion model
8) Nowcasting model
9) Global wave hindcast and assimilation/forecast system
10) Regional wave hindcast and forecast system
11) Mesoscale wave hindcast and forecast system
12) Mesoscale models for sea surge
13) Global ocean model
14) Regional Ocean model
15) Mesoscale Shelf -seas model
16) Global single column (site specific) model
17) Mesoscale single column (site specific) model.

The global atmospheric model runs with 2 different data cut-off times:

- 2 hours (forecast run); and
- 7 hours (update run).

The latest update run provides initial starting conditions for the forecast runs of the global atmospheric model. The global atmospheric model provides surface boundary conditions for the global and regional wave and ocean models. It also provides lateral boundary conditions for the mesoscale model. The mesoscale forecast model is run four times a day and provides surface boundary conditions for the sea-surge model and the mesoscale wave model.. The global wave model provides lateral boundary conditions for the regional and mesoscale wave model. The global and mesoscale models provide forcing data for the global and mesoscale single column models. The transport and dispersion model is run when needed.

7.1 System run schedule

Run	Model	Data Hindcast assimilation		Forecast cut-off		Product boundary available values	
G00	Global atmosphere	2100-0300	-	T+120	0150	0230 & 0405	-
W00	Regional wave	-	12-00	T+36	0150	0345	G18, G00
W00	Global wave	1200-2400	12-00	T+120	0300	0420	G18, G00
C00	Preliminary single column			T+36	0150	0300	G00
C00	Global single column			T+120	0300	0600	G00
M00	Mesoscale atmosphere	2230-0130	-	T+36	0200	0240	G00
W00	Mesoscale wave	-	18-00	T+36	0200	0300	M18, M00
E00	Mesoscale sea surge			T+36	0200	0250	M18, M00
C00	Mesoscale single column			T+36	0200	0400	M00
S00	Stratospheric atmosphere	2100-0300	-	T+6	0450	-	-
O00	Global ocean	24 hours	-	T+144	0500	0530	G00
N00	Regional ocean	24 hours	-	T+120	0500	0540	G00, O00
L00	Mesoscale shelf-seas	-	24 hours	T+36	0525	0545	M00
M03	Mesoscale atmosphere	0130-0430	-	T+4	0700	-	G00
U00	Global atmosphere	2100-0300	-	T+9	0710	-	-
G06	Global atmosphere	0300-0900	-	T+36	0750	0840	-
C06	Preliminary single column			T+36	0750	0900	G06
M06	Mesoscale atmosphere	0430-0730	-	T+36	0800	0840	G06
W06	Mesoscale wave	-	00-06	T+36	0800	0900	M00, M06
E06	Mesoscale sea surge			T+36	0800	0850	M00, M06
C06	Mesoscale single column			T+36	0800	1000	M06
U06	Global atmosphere	0300-0900	-	T+9	1300	-	-
SST	Sea-surface temperature analysis	0000-2359		-	1310	-	-
M09	Mesoscale atmosphere	0730-1000	-	T+4	1315	-	G06
G12	Global atmosphere	0900-1500	-	T+120	1350	1430 & 1605	-
W12	Regional wave	-	00-12	T+36	1350	1545	G06, G12
W12	Global wave	0000-1200	00-12	T+120	1500	1620	G06, G12
C12	Preliminary single column			T+36	1350	1500	G12
C12	Global single column			T+120	1500	1800	G12
M12	Mesoscale atmosphere	1030-1330	-	T+36	1400	1440	G12
W12	Mesoscale wave	-	06-12	T+36	1400	1500	M06, M12
E12	Mesoscale sea surge	-	06-12	T+36	1400	1450	M06, M12
C12	Mesoscale single column			T+36	1400	1600	M12
S06	Stratospheric atmosphere	0300-0900	-	T+6	1625	-	-
U12	Global atmosphere	0900-1500	-	T+9	1915	-	-
M15	Mesoscale atmosphere	1330-1630	-	T+4	1930	-	G12
G18	Global atmosphere	1500-2100	-	T+36	1955	2045	-
C18	Preliminary single column			T+36	1955	2105	G18
M18	Mesoscale atmosphere	1630-1930	-	T+36	2005	2045	G18
W18	Mesoscale wave	-	12-18	T+36	2005	2105	M12, M18
E18	Mesoscale sea surge	-	12-18	T+36	2005	2055	M12, M18
C18	Mesoscale single column			T+36	2005	2200	M18
S12	Stratospheric atmosphere	0900-1500	-	T+48	2110	2130	-
S18	Stratospheric atmosphere	1500-2100	-	T+6	0020	-	-
M21	Mesoscale atmosphere	1930-2230	-	T+4	0030	-	G18
U18	Global atmosphere	1500-2100	-	T+9	0100	-	-

N.B. The global atmosphere and wave model are run out to T+144 for backup purposes only.
The regional wave model is run out to T+48 for backup purposes only.

7.2 Medium-range forecasting system (4-10 days)

7.2.1 Data assimilation, objective analysis and initialisation

Analysed variables	Velocity potential, stream function, unbalanced pressure and relative humidity.
Analysis domain	Global.
Horizontal grid	Half model resolution (see 7.2.2).
Vertical grid	Same levels as forecast model (see 7.2.2).
Assimilation method	3D variational analysis of increments (Lorenc *et al*. 2000). Data grouped into 6-hour time windows centred on analysis hour for quality control.
Assimilation model	As global forecast model (see 7.2.2).
Assimilation cycle	6 hourly.
Initialisation	Increments are initialised using a digital filtering (Lynch 1997) technique involving forward and backward integration of a perturbation forecast model over a 6-hour period (T–3 to T+3). The initialised increments are inserted directly at T+0.

7.2.2 Forecast model

Basic equations	Non-hydrostatic finite difference model with height as the vertical co-ordinate. Full equations used with (virtually) no approximations. Suitable for running at very high resolution.
Independent variables	Latitude, longitude, eta (η), time.
Primary variables	Horizontal and vertical wind components, potential temperature, pressure, density, specific humidity, specific cloud water (liquid and frozen).
Integration domain	Global.
Horizontal grid	Spherical latitude-longitude with poles at 90°N and 90°S. Resolution: 0.56° latitude and 0.833° longitude. Arakawa 'C'-grid staggering of variables.
Vertical grid	38 levels Charney-Philips grid staggering of variables. The normalised vertical co-ordinate η is hybrid in height, varying from $\eta = 0$ at the surface to the top level at $\eta = 1$, where zero vertical velocity w is applied. The lowest level is purely terrain following and there is a smooth (quadratic) transition to a specified number of 'flat' upper levels where the height of each point at a level is constant.
Integration scheme	Two time-level semi-Lagrangian advection with a pressure correction semi-implicit time stepping method using a Helmoltz solver to include non-hydrostatic terms. Model time-step= 1200 s.
Filtering	Spatial filtering of winds and potential temperature in vicinity of poles.
Horizontal diffusion	Fourth order diffusion along η surfaces of winds, specific humidity and potential temperature.
Vertical diffusion	Second-order diffusion of winds only between 500 and 150 hPa in the tropics (equatorward of 30°).
Divergence damping	Nil.
Orography	GLOBE orography dataset. 1 km data, averaged to 10 km. Before it is used in the model, the data are filtered using a sixth-order low-pass implicit tangent filter, constrained so that the filtering is isotropic in real space.
Surface classification	Sea: global SST analysis performed daily;

Sea ice: analysis using NCEP SSM/I.

Physics parametrizations:

a) Surface and soil Met Office Surface Exchange Scheme (MOSES 2; Cox *et al.* 2001) which includes:

- Surface heterogeneity – it is possible to run with a multiple tiled surface. Each tile has different surface properties and the surface energy and water balance are aggregated across the tiles. Currently one tile is used in the global model and there are nine tiles in the mesoscale model. Multiple tiles in the global model are an option for the future.
- Vegetation – new Advanced Very-High Resolution Radiometer (AVHRR) vegetation maps are used. Vegetation-dependent parameters are calculated as model runs from vegetation height and leaf area index.
- Evaporation – surface resistance to evaporation from bare soil is reduced and an exponential root depth distribution is introduced.
- Canopy model – the heat capacity and coverage for vegetation has been reformulated.
- Surface energy balance – changes have been made to eliminate the surface temperature dependence on the upward blackbody long-wave radiation. This smoothes steps in the surface net radiation that otherwise arise whenever the atmospheric radiation scheme is used (once every nine model time steps).
- Improved numerical formulae for the soil hydrology and thermodynamics.

b) Boundary layer Non-local in unstable regimes.

The vertical diffusion coefficients are specified functions of height over a diagnosed mixed-layer depth that are scaled on both the surface and cloud-top turbulence forcing and an explicit parametrization of entrainment at the boundary-layer top is included.

This allows more physical direct coupling between the turbulence forcing of unstable boundary layers and the transports generated within them (rather than the Ri-based scheme that relates fluxes to the local gradients within the layer) and so is numerically more robust.

c) Cloud/precipitation Large scale precipitation with prognostic ice microphysics.

The new scheme employs a more detailed representation of the microphysics occurring within clouds. Water is contained in vapour, liquid, ice and rain categories, with physically based parametrization of transfers between the categories. The ice content becomes a prognostic variable within the model, rather than one diagnosed from a cloud scheme (Wilson and Ballard 1999).

Vertical gradient area large-scale cloud scheme.

The standard Smith (1990) large-scale cloud scheme returns a cloud volume fraction which is assumed to take up the entire vertical depth of the grid box and is therefore equal to the cloud area fraction. The vertical gradient method performs the standard Smith cloud calculation at three heights per grid box (on the grid level and equally spaced above and below it), using

	interpolation of input data according to the estimated sub-grid vertical profiles. Weighted means are then used to calculate the volume data for the grid box, while the area cloud fraction is taken to be the maximum sub-grid value. This modification allows the area cloud fraction to exceed the volume fraction and hence the radiation scheme, which uses area cloud, can respond to larger cloud area coverage and smaller in-cloud liquid water paths than the standard scheme would produce.
d) Radiation	Edwards-Slingo radiation scheme with non-spherical ice spectral files. Ice crystals are modelled as planar polycrystals with sizes related to the temperature (Kristjansson *et al.* 2000). Gaseous transmission treated using correlated-k methods (Cusack *et al.* 1999) with 6 bands in the short wave, 9 in the long wave (Cusack *et al.* 1999 has 8 in the long wave, but we split one of these in HadAM4 and this configuration has gone into the New Dynamics). The CKD continuum model is used (Clough *et al.* 1989) . Fractional cloud is treated as in Geleyn and Hollingsworth (1979) with convective and large-scale cloud distinguished.
e) Convection	Convection with convective available potential energy (CAPE) closure, momentum transports and convective anvils. Diagnosis of deep and shallow convection; based on the boundary layer type diagnosis adopted in the Lock *et al.* (2000) boundary layer scheme. Convective cloud base defined at the LCL (and boundary layer scheme prevented from operating above this, so no longer overlaps with convection scheme). New parametrization for convective momentum transports, based on a flux-gradient relationship. This is obtained from the stress budget by parametrizing the terms (by analogy with scalar flux budgets) such that there is a gradient term associated with the mean wind shear (involving an eddy viscosity) and a non-gradient term associated with the transport (using a mass flux approximation). New cloud-base closures for thermodynamics and momentum transport. The thermodynamic closure for shallow convection follows Grant (2001) in relating the cloud-base mass flux to a convective velocity scale. For deep convection, the thermodynamic closure is based on the reduction to zero of CAPE over a given timescale (based on Fritsch and Chappell 1980). These closures replace the standard buoyancy closure which has found to be both noisy and unreliable. The momentum transport closure for deep and shallow convection is based on the assumption that large-scale horizontal pressure gradients should be continuous across cloud base. Parametrised entrainment and detrainment rates for shallow convection, obtained (Grant and Brown 1999) using similarity theory by assuming that the entrainment rate is related to the rate of production of TKE.
f) Gravity-wave drag	Gravity-wave drag (GWD) scheme which includes flow blocking. Strictly the new parametrization is best described as a sub-grid orography scheme. It consists of a GWD bit (due to flow over) and a non-GWD bit (the flow-blocking bit, due to flow around). The new sub-grid-scale orography (SSO) scheme uses a simplified gravity wave drag scheme and includes a flow-

blocking scheme. The new scheme is thus more robust and applies much more drag at low-levels.

7.2.3 Numerical weather prediction products

Increasingly, output is automatically generated from the NWP output, with little or no human intervention. Examples include outputs available on the Met Office web site for forecasts for world cities up to five days ahead.

7.2.4 Operational techniques for application of NWP products

Model Output Statistics (MOS) products are generated from the 0000 UTC and 1200 UTC runs of the global model for forecasts out to 6 days ahead. Kalman filters are applied to the model forecast data to create the day-maximum and night-minimum temperature forecasts for 800 stations world-wide and probability of precipitation (PoP) over 6- and 12-hour periods for 300 European stations. These Kalman-filtered forecasts are stored in a relational database called FSSSI (Forecasting for Specific Sites: System Implementation). Observations (also stored in the database) are used to update the Kalman filters. The Kalman-filtered forecasts are then sent to other product-generating systems where the data are formatted into end products. Kalman filters are also applied to raw ensemble data from the 1200 UTC ECMWF EPS model creating day-maximum, night-minimum temperature and 10-m wind-speed Kalman-filtered forecasts out to 10 days ahead. These forecasts are stored in FSSSI and are used in producing end products (see section 7.2.5).

7.2.5 Ensemble prediction system

The ECMWF Ensemble Prediction System (EPS) is utilised for medium-range forecasting. Ensembles are also run for monthly and seasonal forecasts (see Sections 7.5 and 7.6). Output from the EPS is post-processed to provide forecasters with numerous chart displays including spaghetti diagrams, ensemble means, individual ensemble members, clusters and extra-tropical cyclone tracks. New products added this year include charts of ocean significant wave height probabilities and tropical cyclone products exploiting the new tropical singular vector perturbations implemented in the EPS by ECMWF. For each identified tropical cyclone, forecast tracks in the ensemble members are plotted, and strike probability charts (similar to those produced by the National Hurricane Center in Miami) are generated automatically. Probability forecasts for specific synoptic sites are stored in the FSSSI database (see 7.2.4). A Kalman Filter is employed to correct for local biases, and derive maximum and minimum temperatures, for over 260 sites world-wide. Ensemble probabilities are calibrated to optimise performance using Rank Histogram verification (Hamill and Colucci 1997). Operational verification system shows that both the Kalman Filter and the calibration system lead to significant improvements in probabilities compared to direct ensemble output. Verification has this year been upgraded to include Brier Skill measured relative to climatological probabilities and to monitor ensemble performance over multiple seasons and years. The EPS is also scanned daily for probabilities of severe weather (severe gales, heavy rain or snow) and issues automatic alerts to forecasters when defined probability thresholds are exceeded. This system incorporates considerable calibration to assess probabilities explicitly in the form required to support the UK National Severe Weather Warning Service.

7.3 Short-range forecasting system (0-72 hours): mesoscale model

7.3.1 Data assimilation

The data assimilation scheme for the mesoscale model is similar to that for the global model, except in the following:

Analysis variables	As global model (see 7.2.1), but also includes aerosol content.
Analysis domain	As model integration domain (see 7.3.2).
Horizontal grid	Full model resolution (see 7.3.2).
Vertical grid	As model levels.
Assimilation method	3D variational analysis of increments for ‘conventional’ data (Lorenc *et al.* 2000) with nudging for cloud and rainfall data. Data grouped into 3-hour time windows centred on analysis hour for quality control.
Assimilation model	As mesoscale forecast model (see 7.3.2).
Assimilation cycle	Increments from ‘conventional’ data are introduced gradually into the model using an Incremental Analysis Update (Bloom *et al.* 1996) over a 2-hour period (T–1 to T+1), while increments from cloud and rainfall data are added by nudging.
Data	Screen temperature, humidity, visibility and surface wind data are assimilated by the mesoscale model. A 3-dimensional ‘MOPS’ cloud fraction analysis, derived from satellite imagery and surface reports, is assimilated (Macpherson *et al.* 1996). An hourly precipitation rate analysis, derived from radar, is assimilated by latent-heat nudging (Jones and Macpherson 1997). A weekly analysis of soil moisture content is performed from ‘data’ produced by the ‘MORECS’ agricultural model for the UK.

7.3.2 Forecast model

The mesoscale model is identical to the global model in all respects, except the following:

Integration domain	The British Isles and all surrounding sea areas, near-continental Europe and southern Norway (approximately 64ºN-44ºN, 12ºW-13ºE).
Horizontal grid	Spherical rotated latitude-longitude with pole at 37.5ºN, 177.5ºE. Resolution: 0.11º.
Time step	Adjustment time step = 25 s; advection time step = 75 s; physics time step = 300 s.
Horizontal diffusion	Linear fourth-order with co-efficient K = 1.9 x 10^6 for winds, liquid water, potential temperature and total water content. No diffusion where co-ordinate surfaces are too steep (near orography).
Vertical diffusion	None.
Orography	A new simpler and more robust sub-gridscale orography scheme. Orographic roughness parameters derived from 100-m data.
Boundary values	Specified from global forecast model with the same data time (forecasts from 00, 06, 12 and 18 UTC).

Physics parametrizations:

a) Surface	Met Office Surface Exchange Scheme (MOSES II; Cox *et al.* 1999), which includes:

	• Penman-Monteith surface flux formulation with a ‘skin’ surface temperature; • A 4-layer coupled soil hydrology and thermodynamics model; • An interactive canopy resistance model; • A tile scheme – each land grid box can be made up of a mixture of 8 surface types (except those classified as land-ice). Land use characteristics are based on AVHRR vegetation maps (horizontal resolution 25 m for the UK, 1 km otherwise).
b) Boundary layer	A new turbulent mixing scheme (Lock *et al.* 2000; Martin *et al.* 2000). Includes representation of non-local mixing driven by both surface fluxes and cloud-top processes in unstable layers, either coupled to, or decoupled from the surface; also includes an explicit entrainment parametrization. A moist conserved variable formulation is used – suitable for both dry and cloud layers.
c) Cloud/precipitation	Cloud ice is treated prognostically with 11 transfer terms between cloud ice, liquid and precipitation products (Wilson and Ballard 1999).
d) Radiation	Edwards-Slingo (1996) flexible two-stream code. Calculated on chequerboard pattern for every other grid box and heating rates interpolated from the same land-sea types. Updated hourly with solar angle updated at each time step.
e) Convection	Updated version of Gregory and Rowntree (1990) scheme to include downdraught parametrization and revised evaporation formulae, dependent on the precipitation rate.
f) Gravity-wave drag	None.

7.3.3 Operational techniques for application of NWP products

Output is increasingly automatically generated from the NWP output, with little or no human intervention. The Site Specific Forecast Model (SSFM) is used more and more to provide output to our many customers with data direct from the models; our OpenRoad service forecasting road surface conditions is an example.

7.4 Specialized forecasts

7.4.1 Nowcasting system

Nimrod produces analyses and forecasts of precipitation and supplementary weather parameters (including precipitation type, visibility, snow probability and lightning rate) at 2-km resolution for the period T+0 to T+6 hours. Forecasts are produced using a combination of linear extrapolation and model wind advection with precipitation forecasts from the mesoscale model used to introduce an element of growth/decay. In addition, analyses and forecasts of cloud amount (3-D), cloud-base and cloud-top height, wind speed and direction are generated. These products are generated hourly at a resolution of 15 km. The Nimrod cloud and precipitation analyses are used as inputs to the mesoscale model assimilation scheme.

Grid	UK national grid: 2- and 5-km resolution for precipitation products; 15-km resolution for cloud products. The domain is an approximation to the mesoscale model domain (roughly 44^{o} N-64^{o} N, 12^{o} W-13^{o} E).
Data inputs	Radar imagery (from the network of 15 sites within the UK, Republic of Ireland and Jersey), Meteosat visible and infrared imagery, mesoscale model forecast fields and surface weather reports.

Forecast time step	5 minutes for precipitation forecasts; 60 minutes for cloud and visibility forecasts.
Special features	Radar rain rates automatically corrected for the effects of bright-band, range and orographic growth, using a physically-based method (Kitchen *et al.* 1994).

7.4.2 Global ocean model – FOAM (Forecasting Ocean Assimilation Model)

Model type	Developed from Bryan-Cox ‘level’ model on Arakawa B-grid. Includes a Kraus-Turner mixed-layer scheme, and a thermodynamic/simple advection sea-ice model.
Integration domain	Global.
Horizontal grid	1° x 1°.
Vertical grid	20 levels; 10 of the levels are in the top 300 m, the deepest is at 5192 m.
Data assimilation	Based on the Met Office analysis correction scheme. Assimilates temperature profile data, and sea-surface temperature data (in-situ and AVHRR). Gridded SSM/I sea-ice concentration data are assimilated, using a nudging technique.
Surface fluxes	From the global NWP model, 6-hourly.

7.4.3 Wave hindcast and forecasting system: global wave model

Model type	Coupled-discrete (SWAMP 1985)
Integration domain	Global
Grid	Spherical latitude-longitude from 80.2778°N to 79.166°S Resolution: 5/9° latitude, 5/6° longitude
Frequency resolution	13 frequency components spaced logarithmically between 0.04 Hz and 0.324 Hz
Direction resolution	16 equally spaced direction components
Data assimilation	ERS-2 altimeter wave-height observations can be assimilated onto the global wave model using the altimeter wind speed to separate wind-sea and swell. The assimilation scheme (Thomas 1988; 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 analysed wave height, the model wind-sea matches the analysed wind speed, and the pattern of the spectrum remains similar to that before assimilation. At present, no data are assimilated.
Integration scheme	Modified Lax-Wendroff. Source terms time step = 1800 s; advection time step is frequency dependent
Boundary forcing	Winds at 10 m, updated hourly
Surface classification	Sea-ice analyses as in the global model
Physics parametrizations	Linear growth (Phillips 1958); exponential growth (Snyder *et al.* 1981); white-capping dissipation (Komen *et al.* 1984). Non-linear transfer of wave energy is parametrized by enforcing JONSWAP spectral shape on the wind-sea. A parametrization of directional relaxation in turning winds is included, and a term for the great-circle turning of swell energy is applied. For wind speeds lower than 7.3 ms^{-1}, a parametric growth term is used to calculate wind-sea growth. For all but actively growing wind-sea, the dissipation coefficient is reduced by one half the specified value. Shallow-water terms are included (shoaling, bottom friction, refraction).

7.4.4 Regional ocean model – FOAM (Forecasting Ocean Assimilation Model)

Model type	Developed from Bryan-Cox ‘level’ model on Arakawa B-grid. Includes a Kraus-Turner mixed-layer scheme, and a thermodynamic/simple advection sea-ice model.
Integration domain	Atlantic/Arctic.
Horizontal grid	1/3° x 1/3°. Rotated grid with pole at 17°N 56°E
Vertical grid	20 levels; 10 of the levels are in the top 300 m, the deepest is at 5192 m.
Data assimilation	Based on the Met Office analysis correction scheme. Assimilates temperature profile data, and sea-surface temperature data (in-situ and AVHRR). Gridded SSM/I sea-ice concentration data are assimilated, using a nudging technique. Altimeter data are assimilated following Cooper and Haines (1996).
Surface fluxes	From the global NWP model, 6-hourly
Boundary data	From global FOAM

7.4.5 Wave hindcast and forecasting system: regional wave model

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

Model type	Coupled discrete; depth dependency specified to 200 m with 2-m resolution.
Integration domain	European continental shelf, and Mediterranean, Baltic and Black Seas.
Grid	Spherical latitude-longitude from 67.7°N to 30.5°N and from 14.1°W to 41.9°E. Resolution: 0.25° latitude, 0.4° longitude.
Source terms time step	1800 s.
Boundary forcing	1) winds at 10 m, updated hourly; 2) spectral values at lateral boundaries from the global wave model, updated hourly.
Surface classification	No sea ice.
Physics parametrizations	Identical to the global model without great-circle tuning of swell.

7.4.6 Wave hindcast and forecasting system: local wave model

The wave model uses the same physics as the regional wave model with the addition of time-varying wave-current interactions, taking surface currents from the operational storm-surge model. The model is set up at 1/9° by 1/6° resolution covering 48°N to 63°N and 12°W to 13°E, the same grid as the operational storm-surge model. The model is run four times daily for a 48-hour forecast under mesoscale 10-m winds. A separate 5-day forecast, without currents, is run twice daily using global-model winds.

Model type	Coupled discrete; depth dependency specified to 200 m with 2-m resolution
Integration domain	North-West European continental shelf
Grid	Spherical latitude-longitude from 48°N to 63°N and 12°W to 13°E. Resolution: 1/9° latitude, 1/6° longitude
Boundary forcing	1) 10-m winds from the mesoscale NWP model, updated hourly (for 48-hour forecast, four times daily). Winds from the global NWP model for 120-hour forecast, twice daily) 2) Spectral values at lateral boundaries from the global wave model, updated hourly

Surface classification	No sea ice. Surface currents from the operational storm-surge model, updated hourly (not used in the 5-day forecast)
Physics parametrizations	Identical to the global model, without great-circle turning of swell, plus calculation of the effect of time-varying currents on wave-energy spectrum.

7.4.7 Shelf-seas forecast model

The Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) baroclinic shelf-seas model (Holt 2002), covering the NW European shelf area. The model runs once daily for a 24-hour hindcast, followed by a 48-hour forecast. There is no data assimilation.

Model type	Baroclinic piecewise parabolic advection scheme, Mellor Yamada turbulent mixing. Hybrid co-ordinate.
Integration domain	North-West European continental shelf.
Grid	Spherical latitude-longitude from 40°N to 65°N, and from 20°W to 13°E. Resolution 1/9° latitude, 1/6° longitude
Boundary forcing	1) Hourly winds and pressures, 6-hourly averaged heat flux from global NWP model; 2) Deep-ocean temperature and salinity profile, barotropic current and elevation from atlantic FOAM model 3) River inflows – daily climatology, data provided from Environment Agency. 4) Tidal elevations from 15 harmonic constituents.
Surface classification	No sea ice; no wetting or drying.

7.4.8 Storm-surge model

A depth-averaged storm-surge model, developed by the Proudman Oceanographic Laboratory, is run operationally on behalf of DEFRA (the Department of the Environment, Food and Rural Affairs) for the Storm-Tide Forecasting Service. The model is implemented on a grid at 1/9° by 1/6° resolution covering 48°N to 63°N, 12°W to 13°E, and is forced at the deep-ocean boundaries by 15 tidal harmonic constituents. The model is run 4 times daily, using hourly values of surface pressure and 10-m winds from the mesoscale NWP model to provide a 36-hour forecast.

7.4.9 Tropical cyclone forecasts

Initialisation of tropical cyclones is achieved by the creation of bogus data which are fed into the numerical forecast model. Tropical cyclone advisory bulletins received on the GTS from various tropical cyclone warning centres are used to provide the input data to this process. The creation of tropical cyclone bogus data is totally automated, but forecasters in the National Meteorological Centre (NMC) at the Met Office have the facility to over-ride the automatic system and create their own bogus data, if required. Full details of the bogus technique may be found in Heming *et al.* (1995).

Tropical cyclone guidance products based on model forecasts are issued twice per day for all areas of the globe. These take the form of text bulletins disseminated on the GTS and Met Office WWW site.

7.4.10 Stratospheric model

A stratospheric configuration of the operational global data assimilation and forecast system has been run at the Met Office for a number of years. It is based on the system described in section 7.2, but with additional stratospheric levels, and lower horizontal resolution. The data assimilation scheme uses a 3-D variational technique (implemented in November 2000). The “New Dynamics” scheme has not yet been implemented in the stratospheric configuration.

Model type	Low horizontal resolution version of the standard global forecast model (section 7.2), but with additional stratospheric levels
Integration domain	Global
Levels	40 hybrid (pressure) coordinate levels
Grid	Horizontal resolution: 2.5 degrees latitude by 3.75 degrees longitude. Variables staggered on Arakawa B-grid.
Data Assimilation	3-D variational data assimilation scheme (Lorenc *et al.* 2000).

7.4.11 Transport and dispersion model (NAME)

A model for medium- to long-range transport and dispersion (NAME) is available to be run in the event of a major atmospheric release of hazardous pollutants. Applications include: nuclear emergencies, volcanic eruptions, major chemical releases or fires, and the airborne transport of the foot and mouth virus. With a comprehensive chemistry scheme it is also used for understanding and predicting air quality and for episode studies. The model provides forecasts of concentrations in the boundary layer and at upper levels, as well as wet and dry deposition to the surface. It uses analysis and forecast fields from the global and mesoscale atmospheric maintained in on-line archives The NAME model may be run at any time in hindcast or forecast mode.

Model type	Three-dimensional Lagrangian multiple-particle Monte Carlo model simulating the medium- or long-range transport, dispersion, and deposition of airborne pollutants.
Integration domain	Global or UK mesoscale, nested as required.
Model grid	Identical to the global or UK mesoscale models. The transport model can access fields from both input models simultaneously with an option to use the best resolution available at every particle position. The output grids are customer defined and of any resolution.
Dynamical input	Meteorological fields from the global or UK mesoscale models.
Integration scheme	Forward time step, determined by the diffusion scheme near to the source, but with an option for definition by the user at longer ranges.
Parametrization	Range of random walk schemes used to represent mixing due to turbulence, utilising profiles of velocity variances and time scales. Parametrisations include: low-frequency wind meandering, plume rise, gravitational settling, the venting of pollutants from the boundary layer by strong convection, and small-scale entrainment at the boundary-layer top. Loss processes include: radioactive decay, wet and dry deposition, and Foot and Mouth virus loss die to high temperature and low humidity. A detailed chemistry scheme (37 species) includes both dry and aqueous phase reactions.
Special features	Utilises high-resolution (5-km) rainfall rates derived from radar products for detailed wet deposition over NW Europe. Source attribution scheme for identifying the origin of material at a given receptor. Can handle multiple and complex sources.

7.4.12 Trajectory Model

A model for generating trajectories utilising three dimensional wind fields from the Unified Model. Generates two or three dimensional trajectories, either forward or backwards in time. Used for assessing the likely transport of airborne pollutants, or identifying source regions.

Model type	Three-dimensional particle trajectory model.
Integration domain	Global or UK mesoscale, nested as required.
Dynamical input	Meteorological fields from the global or UK mesoscale models.
Integration scheme	Forward or backward timestep.

7.5 Extended range forecasts

Extended range and experimental seasonal range forecasts (Section 7.6) are produced from the same 6-month-range, 9-member Atmospheric General Circulation Model (AGCM) ensemble integrations forced with persisted Sea Surface Temperature (SST) anomalies.

Model: The HadAM3 climate version of the Met Office's Unified Model (UM Vn. 4.5) is used (Pope *et al*. 2000). The resolution used is 2.5^{o} latitude, 3.75^{o} longitude and 19 vertical levels. The time step is 30 minutes. The model is run in a 9-member ensemble once each week with a nominal initialisation time of 0000 UTC each Thursday.

Atmospheric initial conditions: Initial conditions for the ensemble are provided by consecutive operational NWP analyses at 6-hour intervals. The first member being initialised with the 00Z analysis each Tuesday and the final member with the 00Z analysis on the following Thursday.

SST and sea-ice forcing: SST anomalies calculated from the Reynolds SST analysis for the 4-week period lagging the initialisation date by 10 days are persisted throughout the integration, updating every 24hrs. SST forcing is the same for all members. Projected changes in sea-ice cover are also represented.

Treatment of land surface variables: Initial conditions for soil moisture, soil temperature and snow cover are taken from climatology. Land surface exchanges are represented using the Met Office Surface Exchange Scheme (MOSES, Cox *et al.* 1999).

Forecast variables: The main forecast variables are mean, maximum and minimum temperature, accumulated precipitation and sunshine amount averaged over two forecast periods; days 11-17 ahead and days 18-31 ahead (forecasts for the 4-10 day period are provided using the ECMWF Ensemble Prediction Scheme). For each ensemble member, global forecast values are derived from direct averaging of daily model output. For the UK region only, values are also derived using regression equations on the forecast period-averaged mean sea-level pressure field and observed local sea-surface temperature.

Model calibration: Forecast anomalies are expressed relative to a model climatology defined for each month of the year from a set of integrations initialised (using the ERA15 re-analysis) at the beginning of each month over the 15-year period 1979-1993.

Forecast formats: Temperature and rainfall forecasts are mainly presented in terms of equiprobable quintile categories; Well Below, Below, Near Normal, Above, Well Above. Tercile categories are used for some forecasts. The forecast is expressed both in terms of the probability of each category and a single deterministic forecast based on the ensemble mean. For deterministic forecasts an indication of "higher confidence" is provided when the ensemble spread is lower than a pre-determined threshold. In addition to the UK regional forecasts, site-specific products are also produced for a number of sites within Europe.

7.6 Long-range forecasts

The model ensemble system used for long (seasonal) range forecasts is identical to that used for extended range forecasts (Section 7.5).

Forecast variables: Forecasts are provided for anomalies in 3-month-average 850 hPa temperature (as a proxy for surface temperature) and precipitation. Forecasts at zero lead (months 1-3 of the integration) and 1-month lead (months 2-4 of the integration) are produced. Site-specific products are based on monthly mean anomalies to a range of 6 months.

Model calibration: Forecast anomalies are expressed relative to a model climatology defined for each month of the year from a set of 9-member ensemble integrations initialised at the beginning of each season over the 19-year period 1979-1997. The same set of integrations has been analysed to assess seasonal prediction skill and to generate information on long term forecast skill that is provided with each forecast.

Forecast format: The model output is used to generate a number of seasonal forecast products including: maps of forecast anomalies, updated weekly and made available to National Meteorological Services; similar maps, updated on a monthly basis and made available to the general public; site-specific forecasts for various sites in Europe for commercial purposes.

Both probability and deterministic forecasts are produced. For probability forecast maps a two category format is used, i.e. the probability that the anomaly will be above or below zero (based on the ensemble distribution). For deterministic forecast maps the anomaly sign and magnitude is provided (based on the ensemble mean). Products are provided in map format for the globe and a number of regional areas and include information on the long-term skill of the forecast. In addition to the map products site-specific products area also generated for various sites in Europe.

8. Verification of prognostic products

Statistic	Parameter	Area	Verified against	T+24	T+72	T+120
RMS error (m)	Z 500	Northern hemisphere	Analyses	11.18	29.98	56.06
RMS error (m)	Z 500	Southern hemisphere	Analyses	15.24	40.32	70.15
RMS error (m)	Z 500	North America	Observations	12.19	30.47	55.30
RMS error (m)	Z 500	Europe	Observations	13.73	30.22	58.25
RMS error (m)	Z 500	Asia	Observations	14.51	27.95	45.62
RMS error (m)	Z 500	Australia/ New Zealand	Observations	12.98	24.27	41.72
RMS vector wind error (ms^{-1})	W 250	Northern hemisphere	Analyses	4.45	9.66	15.13
RMS vector wind error (ms^{-1})	W 250	Southern hemisphere	Analyses	4.97	10.88	16.66
RMS vector wind error (ms^{-1})	W 250	North America	Observations	6.42	11.65	17.75
RMS vector wind error (ms^{-1})	W 250	Europe	Observations	6.04	11.18	17.95
RMS vector wind error (ms^{-1})	W 250	Asia	Observations	6.23	10.83	14.96
RMS vector wind error (ms^{-1})	W 250	Australia/ New Zealand	Observations	6.36	10.31	15.02
RMS vector wind error (ms^{-1})	W 850	Tropics	Analyses	2.13	3.42	4.12
RMS vector wind error (ms^{-1})	W 250	Tropics	Analyses	3.78	6.65	8.36
RMS vector wind error (ms^{-1})	W 850	Tropics	Observations	4.11	4.97	5.45
RMS vector wind error (ms^{-1})	W 250	Tropics	Observations	5.98	7.61	9.13

† Please note that the figures supplied for the Met Office in the 2001 *WWW Technical Progress Report on the Global Data-Processing System* were in error, having been compiled using only 5 months' data for January-May 2001.

9. Plans for the future

9.1 Computer systems

The relocation of the Met Office headquarters from Bracknell to Exeter will take place during 2003, involving one of the biggest IT moves in Europe, the transition of computing systems taking place over a 9-month period. The new Operations Centre will provide a more robust and resilient infrastructure from within which our computing systems deliver their output.

The Met Office has taken delivery of the first NEC SX-6 supercomputer. Following the move to Exeter the NEC will eventually replace the current Cray T3Es.

Horace will continue to be developed with a LINUX environment. Further enhancements to the fields modification project will also take place. This will allow forecasters to post-process the NWP output.

A project will begin to replace the MS Windows NT operating system on Nimbus with one based on MS Windows XP.

9.2 Data assimilation

Upgrades to the mesoscale data assimilation system during 2003 may include:

- Assimilation of AMSU radiances
- Variational assimilation of cloud fraction data to replace current nudging approach
- Improved consistency of analysis with boundary data from global model, by interpolation of global analysis increments to the mesoscale domain
- Quality Control of visibility observations
- A new daily soil moisture analysis taken from an independent Soil State Diagnosis Model run as part of the Nimrod nowcasting system.

There will be work on developing assimilation within a new European area limited area model. Upgrades to the mesoscale data assimilation system during 2003 may include:

- Introduction of daily updating of soil moisture derived from the Nimrod soil state diagnosis model to replace weekly updating from MORECS data.
- Introduction of a nudging scheme to assimilate soil moisture.

Most work will concentrate on developing our 4DVAR capability for the global model during 2003 in readiness for operational implementation in 2004. The data assimilation will require testing and optimisation activities for porting to the new supercomputing platform, the NEC SX6. Since this will coincide with transition to the new site at Exeter, there will be fewer opportunities for introducing upgrades but potential candidates are:

- Introduction of AIRS temperature and moisture retrievals from the Aqua satellite;
- Introduction of MODIS polar winds;
- A revised ATOVS bias correction strategy (especially for the stratosphere).

9.3 Atmospheric forecast models

Short-range forecasting system

The mesoscale model will be tested for an area including Europe and the north-east Atlantic.

Monthly and seasonal forecast system

The monthly and seasonal forecast systems will change substantially during 2002. Monthly forecast products will be generated from a new 30-day, 51-member coupled ocean-atmosphere model developed at ECMWF. Seasonal forecast products will be generated from a new Met Office coupled ocean-atmosphere seasonal forecast model (GloSea) run in a 40-member ensemble. The GloSea model is based on the HadCM3 climate model. Products with an 80-member multiple-model ensemble comprising output from the GloSea model and the ECMWF system2 model will also be developed.

Stratospheric model

Work is in hand to implement the new dynamical core in the stratospheric model during 2003. Using the updated model, we will seek to demonstrate the benefit of the additional stratospheric levels on the processing of satellite temperature soundings and improvements in the forecast skill.

The stratospheric model is being extended to assimilate ozone measurements, from both operational and research satellite programmes. This work is being done in collaboration with the NERC Data Assimilation Research Centre.

9.4 Ocean, wave and surge forecast models

Wave models

Wave-energy spectra from the ERS-2 synthetic aperture radar observations are routinely retrieved with global coverage, using the iterative retrieval scheme developed by Hasselmann *et al.* (1996) at the Max-Plank Institut für Meteorologie at Hamburg.

Ocean forecast models

A 1/9º model of the Atlantic and Arctic is being developed, nested into the Atlantic FOAM. Data from a pre-operational version of this model may form a contribution to the Global Ocean Data Assimilation Experiment GODAE.

Shelf Seas forecast models

In collaboration with the Proudman Oceanographic Labroatory, a model of the Irish Sea, at 1 nautical mile resolution is being prepared, nested into the Atlantic Margin shelf seas model.

9.5 Nowcasting system

Nimrod will be altered to cope with Meteosat Second Generation (MSG) data. In particular, a new cloud mask, cloud-top height field and cloud-top temperature field will be derived from MSG data. Improved versions of the precipitation type forecast, wind forecast and visibility forecast will be introduced. An improved method of advection for use in the rainfall forecast will be introduced.

9.6 Transport and dispersion model

- Continued development of atmospheric turbulence profiles including free troposphere, boundary layer and urban effects;
- Continued development of a replacement model for dispersion at all ranges;
- Use of ensemble forecast products;
- Improved representation of atmospheric chemistry.

9.7 Tropical cyclone forecasting

Work is underway to identify deficiencies and improve the overall performance of the model in the tropics. It is hoped that this will also result in further improvements to the model's performance in forecasting tropical cyclones.

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