WWW TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA-PROCESSING AND FORECASTING SYSTEM (GDPFS), AND THE ANNUAL NUMERICAL WEATHER PREDICTION (NWP) PROGRESS REPORT FOR THE YEAR 2005

United Kingdom

Met Office (Exeter)

1. <u>Summary of highlights</u>

1.1 Forecast models

Atmosphere

- 18 January 2005 — New physics components were introduced to bring global NWP model parametrizations in line with those used in the latest climate version (HadGEM1). These include: (i) improvements to the mixing in decoupled stratocumulus layers in the non-local boundary layer scheme; (ii) revisions to the large-scale precipitation microphysics; (iii) reduction of CAPE timescale from 1hour to 30 minutes in convection scheme; and (iv) an increase in surface albedo over the Sahara desert.

- 22 February 2005 — The regional North Atlantic European (NAE) Model grid spacing was reduced from 20 km to 12 km.

- 13 April 2005 — A new high-resolution UK model with grid spacing of 4 km was introduced.

- 14 June 2005 — A new surface soil moisture analysis was introduced to the NAE using the soil-state diagnosis model of the Nimrod nowcasting system.

- 17 August 2005 — A new soil moisture nudging scheme was introduced into the global model based on errors in screen level temperature and humidity.

- 13 December 2005 — Data assimilation was introduced to the UK 4-km model with four forecast runs per day from 0300, 0900, 1500 and 2100 UTC.

- 13 December 2005 — The global model grid spacing was reduced from 60 km to 40 km in the horizontal and the vertical levels increased from 38 to 50, all the additional levels in the stratosphere. The model lid was raised from 38 km to 65 km.

Computing system

An enhancement to the NEC SX-6, adding four SX-6 nodes and sixteen SX-8 nodes, was installed and became operational in the first quarter of 2005; it has effectively doubled our supercomputing power.

1.2 Observations, quality control and assimilation

The North Atlantic-European model data assimilation moved to a 3-hour cycle from a 6-hour cycle. The Moisture Observation Processing System (MOPS) was included for the first time; local ATOVS and Meteosat rapid-scan winds were also introduced. The forecast error statistics were revised based upon those used for the UK mesoscale model.

The following data assimilation upgrades were made to the global model:-

8 February 2005	Introduction of latent heat release into Perturbation Forecast model within 4D-Var, accompanied by efficiency changes. MODIS polar orbiting satellite wind observations were introduced.
14 June 2005	Revision of covariance statistics, now based on T+30 – T+6 rather than T+48 – T+24 differences.
17 August 2005	Replacement of Aqua ATOVS sounding data by NOAA-18 ATOVS data. Soil moisture analysis was introduced.
11 October 2005	Replacement of external digital filter initialisation by a weak constraint penalising gravity-wave noise.
13 December 2005	Upgrade from 38 to 50 levels, as required by the corresponding change in model resolution: extra upper level sounding channels switched on and AIRS data temporarily disabled.

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 Z990 - 303
IBM Z800 – 0A2

B) NEC Hall 1
15 SX-6 nodes + 16 SX-8 nodes + 3 TX-7 front-end nodes
NEC Hall 2
19 SX-6 nodes + 3 TX-7 front end nodes
(each SX-6 node & SX-8 node has 8 CPUs)
(each TX-7 node has between 8 & 12 CPUs)

2.1.2 Main Memory

A) 32 Gigabytes on Z990
8 Gigabytes on Z800

B) 32 Gigabytes per SX-6 cluster
64 Gigabytes per SX-8 cluster
24 Gigabytes per TX-7 cluster

2.1.3 Operating system

A) ZOS 1.6

B) Super-UX on SX-6 and SX-8 nodes
RedHat AS LINUX on TX-7 nodes

2.1.4 External input/output devices

A) 1.2 Terabytes of on-line disk storage	B) 26 terabytes online disk storage shared between all nodes

Both systems are LAN attached to desktop PCs, UNIX servers and printers.

Both systems are connected to a Storagetek Powderhorn tape library for system backups and HSM facilities via a SUN Blade server running ACSLS software. The tape library has 18 Storagetek 9840 cartridge drives, 4 Storagetek 9940B cartridge drives and a capacity of 5600 cartridge slots.

2.2 Desktop systems for forecasters

"Horace", a Hewlett-Packard Unix-based HPUX-11 workstation system continues to be used by the Met Office at its Operations Centre in Exeter and at the Royal Air Force Headquarters Strike Command at High Wycombe (Anon., 1999; Radford, 2000). The Royal Navy also use this system at their headquarters in Northwood.

A PC-based production system called Nimbus (McHugh *et al.*, 2000) is used at all front-line Met Office locations in the UK and overseas. This system visualises data for forecasters but is also the main production platform for the creation of products and services to the Met Office customers. All Nimbus systems are linked together and with our new HQ in Exeter by a TCP/IP Wide Area Network (WAN). The systems utilise X400 message switching technologies to distribute data.

A variant of Nimbus software is used by the Met Office to enable deployed forecasters to support military operations throughout Europe and the Middle East. Branded NAMIS, it is used by NATO meteorological communities in a similar role to support both permanent NATO met offices and at deployed locations. Data are supplied via satellite communications through a hub in Germany.

The Met Office increasingly uses its web site to visualise meteorological data and has services available for customers through a secure web server connection. Many meteorological data, ranging from observations through satellite imagery and rainfall radar to NWP, can be made available to customers.

2.3 MASS storage system

The Mass storage system is used to hold the large volume of numerical model data produced on the supercomputer and real time observational data. The system currently holds around 650 terabytes and is expected to hold 1.8 petabytes by April 2008. The current ingestion rate averages 1 terabyte per day.

The system comprises of SUN E6900 server with 1.7 terabytes of high performance disk and 54 terabytes of low cost disk. The tape library is a Storagetek Powerhorn tape silo with 12 Storagetek 9840 cartridge drives (20 gigabyte capacity) and 12 Storagetek 9840B cartridge drives (200 gigabyte capacity).

The system is connected to the Supercomputer, Front-end mainframe and Research Unix servers.

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 2005, excluding newer data types or formats received, but not yet processed for assimilation.

Observation group	**Observation sub-group**	**Items used**	**Daily extraction**	**% 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 AIRS	Radiances directly assimilated with channel selection dependent on surface instrument and cloudiness	2,000,000 160,000	3 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 GOES: SATOB; Meteosat: BUFR; MODIS	GOES 10, 12 MTSAT Meteosat 5, 7	High-resolution IR winds IR, VIS and WV winds IR, VIS and WV winds	120,000 3,000 180,000	7 60 5
	Aqua,Terra	IR,VIS and WV winds (polar)	120,000	5
Satellite-based surface winds	SSMI-13,15 Quikscat	In-house 1DVAR wind-speed retrieval	3,000,000 2,000,000	1 4
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 Météo-France, 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, Exeter).
- 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 World-Wide Web);
- A real-time monitoring capability that provides time series 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 time series 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 (4D-Var)
2. Global atmospheric forecast model
3. Regional atmospheric data assimilation system (3D-Var)
4. Regional atmospheric forecast model
5. Mesoscale atmospheric data assimilation system (3D-Var)
6. Mesoscale atmospheric forecast model
7. Stratospheric global atmospheric data assimilation system (3D-Var)
8. Stratospheric global atmospheric forecast model
9. Transport and dispersion model
10. Nowcasting model
11. Global wave hindcast and assimilation/forecast system
12. Regional wave hindcast and forecast system
13. Mesoscale wave hindcast and forecast system
14. Mesoscale models for sea surge
15. Global ocean model
16. Regional ocean models
17. Nested ocean models
18. Mesoscale Shelf-seas model
19. Nested Shelf-seas model
20. Global single-column (site-specific) model
21. Mesoscale single-column (site-specific) model.
22. Global atmospheric ensemble forecast model (24 members)
23. Regional atmospheric ensemble forecast model (24 members)
24. Local 4km atmospheric 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 regional and mesoscale models. The mesoscale forecast model is run four times a day and provides surface boundary conditions for the sea-surge model, mesoscale wave model and the shelf-seas models. 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+144	0145	0230 & 0405	-
EG00	Global Ensemble			T+36	0240	0440	
W00	Regional wave	-	12-00	T+48	0145	0345	G18, G00
W00	Global wave	1200-2400	12-00	T+144	0300	0420	G18, G00
M00	Mesoscale atmosphere	2230-0130	-	T+48	0205	0240	G00
W00	Mesoscale wave	-	18-00	T+48	0205	0300	M18, M00
E00	Mesoscale sea surge			T+48	0205	0250	M18, M00
Y00	Regional atmosphere	2230-0130	-	T+48	0245	0400	G18
C00	Mesoscale single column			T+36	0245	0400	M00
C00	Preliminary single column			T+36	0250	0400	G00
C00	Global single column			T+144	0315	0600	G00
D00	Regional marine			T+36	0410	0435	
400	Local 4km atmospheric			T+3	0425	0445	
403	Local 4km atmospheric			T+36	0455	0550	
S00	Stratospheric atmosphere	2100-0300	-	T+6	0510	-	-
O00	Global ocean	24 hours	-	T+144	0500	0530	G00
O00	Regional ocean	24 hours	-	T+144	0500	0540	G00, O00
O00	Nested ocean	24 hours	-	T+144	0500	0550	G00, O00
Q00	Mesoscale shelf-seas	-	24 hours	T+48	0545	0620	M00
Q00	Nested shelf-seas	-	24 hours	T+48	0545	0630	M00
U00	Global atmosphere	2100-0300	-	T+9	0635	-	-
Y03	Regional atmosphere	0130-0430	-	T+4	0700	-	G00
M03	Mesoscale atmosphere	0130-0430	-	T+4	0720	-	G00
G06	Global atmosphere	0300-0900	-	T+48	0750	0840	-
M06	Mesoscale atmosphere	0430-0730	-	T+48	0805	0840	G06
W06	Mesoscale wave	-	00-06	T+48	0805	0900	M00, M06
E06	Mesoscale sea surge			T+48	0805	0850	M00, M06
Y06	Regional atmosphere	0130-0730	-	T+48	0845	1000	G00
C06	Mesoscale single column			T+36	0845	1000	M06
C06	Preliminary single column			T+36	0850	1000	G06
EY06	Regional ensemble			T+36	0930	1130	
D06	Regional marine			T+36	0935	1000	
406	Local 4km atmospheric			T+3	0950	1010	
409	Local 4km atmospheric			T+36	1205	1300	
U06	Global atmosphere	0300-0900	-	T+9	1235	-	-
SST	Sea-surface temperature analysis	0000-2359		-	1250	-	-
Y09	Regional atmosphere	0730-1030	-	T+4	1300	-	G06
M09	Mesoscale atmosphere	0730-1030	-	T+4	1320	-	G06
G12	Global atmosphere	0900-1500	-	T+144	1345	1430 & 1605	-
W12	Regional wave	-	00-12	T+48	1345	1545	G06, G12
W12	Global wave	0000-1200	00-12	T+144	1500	1620	G06, G12
M12	Mesoscale atmosphere	1030-1330	-	T+48	1405	1440	G12
W12	Mesoscale wave	-	06-12	T+48	1405	1500	M06, M12
E12	Mesoscale sea surge	-	06-12	T+48	1405	1450	M06, M12
EG12	Global ensemble			T+36	1440	1640	
Y12	Regional atmosphere	1030-1330	-	T+48	1445	1600	G06
C12	Mesoscale single column			T+48	1445	1600	M12
C12	Preliminary single column			T+36	1450	1600	G12

Run	Model	Data Hindcast assimilation	Forecast cut-off	Product boundary available values
C12	Global single column		T+120 1515	1800 G12
D12	Regional marine		T+36 1605	1630
S06	Stratospheric atmosphere	0300-0900 -	T+6 1610	- -
412	Local 4km atmospheric		T+3 1620	1640
415	Local 4km atmospheric		T+36 1650	1745
U12	Global atmosphere	0900-1500 -	T+9 1835	- -
Y15	Regional atmosphere	1330-1630 -	T+4 1900	- G12
M15	Mesoscale atmosphere	1330-1630 -	T+4 1930	- G12
G18	Global atmosphere	1500-2100 -	T+48 1945	2045 -
M18	Mesoscale atmosphere	1630-1930 -	T+48 2005	2045 G18
W18	Mesoscale wave	- 12-18	T+48 2005	2105 M12, M18
E18	Mesoscale sea surge	- 12-18	T+48 2005	2055 M12, M18
Y18	Regional atmosphere	1630-1930 -	T+48 2040	2200 G12
C18	Mesoscale single column		T+36 2045	2200 M18
C18	Preliminary single column		T+36 2050	2205 G18
S12	Stratospheric atmosphere	0900-1500 -	T+48 2120	2200 -
EY18	Regional ensemble		T+36 2130	2330
D18	Regional marine		T+36 2135	2200
418	Local 4km atmospheric		T+3 2150	2210
S18	Stratospheric atmosphere	1500-2100 -	T+6 2320	- -
421	Local 4km atmospheric		T+36 2345	0040
U18	Global atmosphere	1500-2100 -	T+9 0035	- -
Y21	Regional atmosphere	1930-2230 -	T+4 0100	- G18
M21	Mesoscale atmosphere	1930-2230 -	T+4 0120	- G18

N.B. The global atmosphere and wave model are run out to T+168 for backup purposes only.

7.2 Medium-range forecasting system (2-10 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	Same as model grid (see 7.2.2), but resolution is 1.111º latitude and 1.667º longitude
Vertical grid	Same levels as forecast model (see 7.2.2)
Assimilation method	4D variational analysis of increments. A Perturbation Forecast (PF) model and its adjoint represent model trajectories during the data window. The PF model operates on the assimilation grid and is based on the full forecast model but simplified to provide fast linear calculations of small increments for fitting observations. In particular the PF model omits most physics schemes. Data is 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 not initialised explicitly, but gravity wave noise is reduced by use of a weak constraint penalising filtered increments of a pressure based energy norm, similar to the

	method of Gauthier and Thepaut (2001). The initialised increments are inserted directly at T–3.

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 90º N and 90º S. Resolution: 0.556º latitude and 0.833º longitude. Since December 2005 the horizontal resolution has increased to 0.375º latitude and 0.5625º longitude. Arakawa 'C'-grid staggering of variables.
Vertical grid	38 levels and 38km top (50L and 65km top from Dec 2005, with additional levels in the stratosphere.) 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 the vicinity of the 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 30º).
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 sea-surface temperature (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.
- Global model now includes an initialisation of soil moisture using a soil moisture nudging scheme (since Aug 2005).

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 Richardson-number-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 (1996) 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 are 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. However, these data often have value added by forecasters, aided by use of ensemble techniques to provide the best estimate of weather conditions in the medium term.

The Met Office has a Site Specific Forecast Model that takes the raw NWP data and further enhances output to be specific to a site. World cities forecasts to five days on the Met Office and BBC web sites utilise these data in the medium range.

7.2.4 Operational techniques for application of NWP products

The Site-Specific Forecast Model (SSFM) is used to produce site-specific forecasts out to T+144 from NWP data (see section 7.3.4 for more information on SSFM).

Model Output Statistics (MOS) products are also produced, 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. Kalman filters are also applied to raw ensemble data from the 1200 UTC ECMWF EPS model creating day-maximum and night-minimum temperature plus 10-m wind-speed Kalman-filtered forecasts out to 10 days ahead (more information available in section 7.2.5). All these site-specific forecasts are stored in a relational database, FSSSI (Forecasting for Specific Sites: System Implementation) and are used to produce a wide variety of end products.

7.2.5 Ensemble prediction system

The ECMWF Ensemble Prediction System (EPS) is utilised for medium-range forecasting. Output from the EPS is post-processed twice daily to provide forecasters and customers with numerous chart displays including spaghetti diagrams, ensemble means, individual ensemble members and tracks of extra-tropical cyclones. Charts are generated showing grid-point probabilities of wind-speed, precipitation accumulations, temperature anomalies and significant height of ocean waves. Clustering of ensemble members is also provided.

In addition Site-specific probability forecasts of temperature, wind-speed and precipitation are stored in our site-specific database, FSSSI (see 7.2.4). Forecasts of cloud cover and sunshine are available for a limited set of UK sites. A Kalman Filter is employed to correct for local biases, and derive maximum and minimum temperatures, for over 300 sites world-wide. Ensemble probabilities are calibrated to optimise performance using Rank Histogram verification (Hamill and Colucci, 1997). Operational verification shows that both the Kalman Filter leads to significant improvements in probabilities compared to direct ensemble output; the calibration adds a small further improvement for certain products. 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 is calibrated to assess probabilities explicitly in the form required to support the UK National Severe Weather Warning Service. Verification shows that 3 to 4-day forecasts of severe weather have useful probabilistic skill. Most of the skill comes in the form of low-probability warnings.

A new Met Office ensemble prediction system (MOGREPS – see para 7.3.5) is being extended to provide medium-range ensemble forecasts as a contribution to the TIGGE project under THORPEX, but is not yet operational.

7.3 Short-range forecasting system (0-48 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 in the global model (see 7.2.1), but 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 64º N to 44º N, 12º W to 13º E).
Horizontal grid	Spherical rotated latitude-longitude with pole at 37.5º N, 177.5º E. Resolution: 0.11º.
Vertical grid	38 levels and 38km top
Time step	300 s.
Horizontal diffusion	None
Vertical diffusion	None
Orography	A new simpler and more robust sub-gridscale orography scheme. Orographic roughness parameters derived from 1km (based on 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), as for global except:
• 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	As for global
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	As for global with gravity wave drag coefficient 3.00e+03 and critical Froude number of 1 (Webster *et al.*, 2003).

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. Short-range NWP is used throughout the Met Office products and services. These range from direct NWP output to oil industry customers through to the forcing conditions for driving further models such as the Nuclear Accident Model (NAME). 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 and web site forecasts are examples. The SSFM is a relocatable column model that has a free running boundary relaxed back to advection terms provided by either mesoscale or global NWP. It provides a platform for the creation of consistent diagnostic products in addition to the basic NWP output variables, e.g. cloud probabilities, precipitation types.

The single column forecast model is identical to the mesoscale model in all respects, except the following:

Integration domain	Not applicable but can be placed at any location within 3-D model domain
Horizontal grid	Not applicable (1-D model)
Vertical grid	77 levels, lowest model level at 2.5 m
Time step	Physics time steps: radiation = 300 s; other physics = 30 s
Horizontal diffusion	None
Vertical diffusion	None
Orography	Sub-grid linear orographic adjustment scheme to capture flow blocking (Mason and King, 1985)
Boundary values	Specified from mesoscale forecast model with the same data time (forecasts from 0000, 0600, 1200 and 1800 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 9-layer coupled soil hydrology and thermodynamics model;
- An interactive canopy resistance model with urban canopy component;
- 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);
- Interactive anisotropic fetch scheme (radial resolution 6^o for the UK, 12^o otherwise) (Hopwood, 1998);
- Interactive 1-D source area scheme coupled to fetch and tile schemes (Hopwood, 1998).

7.3.5 Short-range ensemble prediction system

A new short-range ensemble prediction system based on the Unified Model was introduced this year. MOGREPS (Met Office Global and Regional Ensemble Prediction System) provides a 24-member regional ensemble covering the North Atlantic and Europe with a grid-length of 24km, running twice daily (0600 and 1800 UTC) to 36 hours ahead (John 2006). A global ensemble with grid-length of 90km runs twice daily (00 and 12 UTC) to 72 hours to provide the boundary conditions for the regional ensemble. Initial condition perturbations are provided through the ETKF (Ensemble Transform Kalman Filter) method calculated using the global ensemble; two stochastic physics schemes are employed to account for model error in assessing forecast uncertainty. Chart-based and site-specific forecast products are provided to forecasters in real-time on an internal web-based system. The system is currently running under *operational trial* and is being assessed daily by forecasters, but is not available for production. It is planned to extend the global ensemble forecasts to 15 days as a contribution to the THORPEX TIGGE project.

7.4 Short-range forecasting system (0-48 hours): North Atlantic European (NAE) model

7.4.1 Data assimilation

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

Analysis variables	As in the global model (see 7.2.1), but includes aerosol content
Analysis domain	As model integration domain (see 7.4.2)
Horizontal grid	Half model resolution (see 7.4.2)
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 UK 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 surface soil-moisture analysis for the NAE takes data from the soil state diagnosis model of the Nimrod nowcasting system.

7.4.2 Forecast model

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

Integration domain	From the North American Great Lakes to the Caspian Sea, central Greenland to northern Africa (approximately 70º N to 30º N, 70º W to 50º E, but distorted due to rotated grid).
Horizontal grid	Spherical rotated latitude-longitude with pole at 37.5º N, 177.5º E. Resolution: 0.11º.
Vertical grid	38 levels and 38km top
Time step	300s
Horizontal diffusion	None
Vertical diffusion	None
Orography	A new simpler and more robust sub-gridscale orography scheme. Orographic roughness parameters derived from 1km (based on 100-m) data.
Boundary values	Specified from global forecast model with the previous data time (T–6, i.e. forecasts from 18, 00, 06 and 12 UTC).

Physics parametrizations:

a) Gravity-wave drag	As for global with coefficient 1.00e+05 and critical Froude number of 4 (Webster *et al.*, 2003).

7.5 Short-range forecasting system (0-48 hours): UK 4-km model

7.5.1 Data assimilation

Data assimilation for the UK 4-km model is similar to that for the NAE model described in 7.4.1.

7.5.2 Forecast model

The UK 4-km model is identical to the NAE model in all respects, except the following:-

Integration domain	The British Isles and all surrounding sea areas, near-continental Europe (approximately 59º N to 48º N, 11º W to 5º E).
Horizontal grid	Spherical rotated latitude-longitude with pole at 37.5º N, 177.5º E. Resolution: 0.036º.
Vertical grid	38 levels and 38km top
Time step	100s
Horizontal diffusion	Fourth order diffusion along η surfaces of winds, specific humidity and potential temperature.
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 NAE forecast model with the previous data time (T–3, i.e. forecasts from 0000, 0600, 1200 and 1800 UTC).

Physics parametrizations:

a) Convection	As NAE except the CAPE closure timescale is not constant but depends on the magnitude of the CAPE. Large values of CAPE effectively inhibits the parametrised treatment of deep convection so that it is explicitly resolved by the dynamics.
b) Gravity-wave drag	As for global with coefficient 3.30e+03 and critical Froude number of 4 (Webster *et al.*, 2003).

7.6 Specialized forecasts

7.6.1 Nimrod nowcasting model

The Nimrod nowcasting system produces analyses and forecasts of precipitation and other weather parameters. These include precipitation type, visibility, (3D) cloud amount, cloud base and cloud top height, wind speed and direction, temperature, gust intensity, towering convection and probabilities of snow, lightening and fog for the period T+0 to T+6 hours, operating on an hourly cycle. Forecasts are normally produced by merging an extrapolation forecast with an NWP model forecast at a resolution of either 5 or 15 km. Rainfall forecasts are also produced on the half hour at 5 km, and at quarter hourly intervals at 2-km resolution. A set of soil moisture products is also produced at 5-km resolution. The Nimrod cloud and precipitation analyses are used as inputs to the mesoscale model assimilation scheme.

Grid	There are two configurations of Nimrod, one covering the UK, and one covering the European area. Both are set up on Transverse Mercator projections, the UK domain covering a domain approximately 44^o N to 64^o N, 12^o W to 13^o W, and the European domain extending from 30^o W to 43^o E at 60^o N and from 10^o W to 25^o E at 35^o N.
Data Inputs	Imagery from the UK and European radar, Meteosat and MSG visible and infrared imagery, NWP model fields (mesoscale model for UK Nimrod, global model for European Nimrod) and surface weather reports.
Forecast time step	5 minutes for precipitation forecasts; 60 minutes for other fields.
Special Features	Radar rain rates automatically corrected for the effects of bright-band, range and orographic growth (Kitchen *et al.*, 1994)

7.6.2 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	1º x 1º
Vertical grid	20 levels; 10 of the levels are in the top 300 m, the deepest is at 5192 m
Data assimilation	Developed from the Analysis Correction scheme of Lorenc *et al.* (1991), including a 2-component inhomogeneous 3-D error covariance model. Temperature and salinity profile data, and sea-surface temperature data (in-situ and AVHRR) are

	assimilated. Gridded SSM/I sea-ice concentration data are also assimilated using a nudging technique (Bell *et al.*, 2000).
Surface fluxes	From the global NWP model, 6-hourly

7.6.3 Wave hindcast and forecasting system: global wave model

Model type	Coupled-discrete (SWAMP, 1985)
Integration domain	Global
Grid	Spherical latitude-longitude from 80.2778ºN to 79.166ºS Resolution: 5/9º latitude, 5/6º 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 to one third of the specified value. Shallow-water terms are included (shoaling, bottom friction, refraction).

7.6.4 Regional ocean models – 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 thermo-dynamic/simple advection sea-ice model.
Integration domain	(1) Atlantic/Arctic; (2) North Atlantic; (3) Mediterranean; (4) Indian Ocean; (5) Antarctic.
Horizontal grid	(1) 1/3º x 1/3º. Rotated grid with pole at 17º N, 56º E; (2) 1/9º x 1/9º. Rotated grid with pole at 42º N, 160º E; (3) 1/9º x 1/9º; (4) 1/3º x 1/3º; (5) 1/4º x 1/4º. Rotated grid with pole at 5º N, 75º E.
Vertical grid	20 levels; 10 of the levels are in the top 300 m, the deepest is at 5192 m.
Data assimilation	Developed from the Analysis Correction scheme of Lorenc *et al.* (1991), including a 2-component inhomogeneous 3-D error covariance model. Assimilates temperature and salinity 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 using a modified version of Cooper and Haines (1996).
Surface fluxes	From the global NWP model, 6-hourly
Boundary data	(1) From global FOAM; (2) from Atlantic/Arctic FOAM; (3) not required; (4) from global FOAM; (5) from global FOAM.

7.6.5 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; Mediterranean, Baltic and Black Seas
Grid	Spherical latitude-longitude from 67.7º N to 30.5º N and from 14.1º W to 41.9º E; resolution: 0.25º latitude, 0.4º 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.

7.6.6 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 1/9º by 1/6º resolution covering 48º N to 63º N and 12º W to 13º 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 48º N to 63º N and 12º W to 13º E. Resolution: 1/9º latitude, 1/6º 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.

7.6.7 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 40º N to 65º N, and from 20º W to 13º E. Resolution 1/9º latitude, 1/6º 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.

7.6.8 Nested coastal ocean model

Model type	POLCOMS: Baroclinic piecewise parabolic advection scheme, Mellor Yamada turbulent mixing; hybrid co-ordinate
(1) Integration domain	NW European shelf seas Medium Resolution Continental Shelf model (MRCS), with western boundary at approximately the 200m depth contour
(1) Grid	Spherical latitude-longitude from 48º N to 62º N and from 12ºW to 13º E. Resolution 1/10º latitude, 1/15º longitude
(2) Integration domain	Irish Sea
(2) Grid	Spherical latitude-longitude from 51º N to 56º N and from 7º W to 2.7º W. Resolution 1/60º latitude, 1/40º longitude
Boundary forcing	1) Hourly winds and pressures, 3-hourly averaged heat flux from mesoscale NWP model; 2) Boundary temperature and salinity profile, barotropic current and elevation from POLCOMS Atlantic Margin model (for (1)) or from MRCS model (for (2)); 3) River inflows – daily climatology, data provided by the Environment Agency
Surface classification	No sea Ice, wetting or drying

7.6.9 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 1/9º by 1/6º resolution covering 48º N to 63º N, 12º W to 13º 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.

7.6.10 Tropical cyclone forecasts

Initialisation of tropical cyclones is achieved by the creation of bogus data that 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 Operations Centre 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 web site (www.metoffice.gov.uk).

7.6.11 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 global configuration described in section 7.2, but with additional stratospheric levels and lower horizontal resolution. The stratospheric model configuration includes a spectral gravity-wave drag parametrization scheme (Scaife *et al*., 2002; Warner and McIntyre, 1999) and a simple methane oxidation scheme. An improved version of the satellite radiance assimilation, including processing of AIRS data, was successfully implemented in early 2005.

Non-operational versions of the stratospheric model have been extended to assimilate ozone and stratospheric water vapour measurements, from both operational and research satellite programmes. This work is being done in collaboration with the NERC Data Assimilation Research Centre, and with the EU-supported ASSET project.

Model type	Low horizontal resolution version of the standard global forecast model (section 7.2), but with additional stratospheric levels
Integration domain	Global
Levels	50 hybrid (height) coordinate levels with Charney-Philips staggering of variables
Grid	Horizontal resolution: 2.5^{o} latitude by 3.75^{o} longitude. Variables staggered on an Arakawa 'C'-grid
Data Assimilation	3-D variational data assimilation scheme (Lorenc *et al.*, 2000)

7.6.12 Transport and dispersion model

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 models maintained in on-line archives. The NAME model may be run at any time in hindcast or forecast mode.

Model type	Three-dimensional Lagrangian particle Monte Carlo model simulating the medium- or long-range transport, dispersion and deposition of airborne pollutants.
Domain	Global or UK mesoscale, nested as required.
Model grid	Identical to the global, UK mesoscale, or crisis-area mesoscale models. The transport model can access fields from three input models simultaneously with an option to use the best resolution available at every particle position. The output grids are user defined and of any resolution.
Meteorological input	Meteorological fields from the global or UK mesoscale models and high-resolution rainfall rates derived from radar.

Integration scheme	Forward Euler solution of the stochastic differential equations governing the particle positions, with time step determined by the diffusion scheme near to the source, but with an option for definition by the user at longer ranges.
Parametrizations	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 due 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 north-west Europe. Source attribution scheme for identifying the origin of material at a given receptor. Can handle multiple and complex sources.

7.6.13 Trajectory model

A model for generating trajectories is also available. It utilises three-dimensional wind fields from the Unified Model and 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.
Domain	Global or UK mesoscale, nested as required.
Meteorological input	Meteorological fields from the global or UK mesoscale models.
Integration scheme	Forward Euler.

7.7 Extended-range forecasts

Extended-range forecast products are generated using output from the ECMWF monthly-range ensemble forecast system.

Model: Output from the ECMWF coupled ocean-atmosphere 51-member monthly-range ensemble system (Vitart, 2003) is used. The system comprises the latest cycle of the ECMWF deterministic forecast model coupled using the OASIS interface (Terray *et al.*, 1995) to the HOPE ocean model (Wolff *et al.*, 1997). The atmospheric component is run at T_L159 resolution (1.125° x 1.125°) with 40 levels in the vertical. The model is currently run once each week from initial conditions at 0000 UTC on Thursday.

Forecast products: Met Office post-processing is performed for mean, maximum and minimum temperature, precipitation and sunshine amount averaged/accumulated over three forecast periods; days 5-11 ahead, days 12-18 ahead and days 19-32 ahead (for the UK region forecasts for the 5-11 day period are generated using the ECMWF 10-day EPS).

Products include global probability forecasts and detailed forecasts for the 10 UK climate districts. Global probability products are provided in the form of 1) probability maps for tercile categories of temperature and precipitation, and 2) for specific regions, probability histograms for quintile categories (well-below, below, near, above, and well-above the climate normal for the region and time of year). For the 10 UK climate districts temperature and rainfall forecasts are generated in terms of quintile categories. Tercile categories are used for sunshine. The UK forecasts are expressed both in terms of the probability of each category and a deterministic forecast based on either the ensemble mean or the most probable quantile. For deterministic forecasts an indication of "higher confidence" is provided when the ensemble spread is lower than a pre-determined threshold.

Model calibration: A hindcast dataset, with the same start time and valid period as the forecast, is available ahead of each forecast in a 5-member ensemble. For forecast calibration, the Met Office's post-processing uses a rolling 12-year hindcast period, ending with the year prior to the forecast year.

7.8 Long-range forecasts

Seasonal forecasts to 6-months ahead are generated each month using the Met Office's 41-ensemble coupled ocean-atmosphere global seasonal prediction system (known as GloSea). GloSea is based on the HadCM3 climate model. The GloSea system is initialised using an ensemble of ocean analyses and runs on the ECMWF computing facility in parallel configuration with the ECMWF system2 seasonal prediction model as part of a developing European multi-model system (the European Seasonal to Interannual Prediction Project – Euro-SIP). Further details of the GloSea system are provided below. A performance assessment is provided by Graham *et al*. (2005).

Model: The GloSea model is a version of the HadCM3 climate model (Gordon *et al*., 2000) with a number of adaptations for seasonal forecasting purposes. Key specifications are:-

> *Ocean resolution*: A stretched north-south ocean grid is used in which a grid spacing of 1.25° in both the meridional and zonal directions improves to 0.28° in the meridional direction in the tropics. The number of vertical levels is 40.
> *Atmosphere resolution*: The atmospheric component of GloSea is the HadAM3 AGCM which has a horizontal resolution of 2.5° latitude and 3.75° longitude with 19 vertical levels.
> *Coastal tiling*: GloSea employs a coastal tiling scheme which enables an atmosphere grid box to represent a mix of both land and ocean. The scheme allows the ocean model to have a coastline determined by the ocean grid, rather than by the lower resolution atmosphere grid - thus yielding a much improved resolution of land/sea features.
> *Ocean Data Assimilation (ODA)*: The ODA scheme is based on the Met Office FOAM system, which uses a form of optimal interpolation with the addition of a novel bias correction scheme to correct for imbalances caused by assimilating accurate subsurface thermal data when the analysis is forced by relatively inaccurate surface wind stresses. This reduces analysis errors in the equatorial Pacific.
> *Ensemble perturbations*: Perturbations are applied to the GloSea ocean component only, using a two-stage approach. Firstly, wind stress perturbations (selected randomly from a specified perturbation set) are applied during the assimilation phase to produce 5 alternative 3-D ocean states. Secondly, perturbations are applied to the SST field of each of the 5 ocean states to derive a total of 41 perturbed ocean states for initialising the forecast ensemble.

GloSea forecasts are initialised from the first day of each month and run out to 6 months ahead.

Forecast products: A range of forecast products is made available to NMSs, regional climate outlook fora, UK government agencies, the public and commercial companies.

Forecasts are provided for anomalies in 3-month-average 2-metre temperature and precipitation, at one-, two- and three-month leads - corresponding to months 2-4, 3-5 and 4-6 of the integration. A probabilistic format is used giving probabilities for equiprobable tercile categories and also for two outer-quintile categories (20th and 80th percentile). In addition to these probability products, maps indicating the most probable tercile category are also provided. Verification information indicating forecast performance has been generated, using WMO guidelines, and is displayed alongside the forecasts. Forecast products for monthly-mean Sea Surface Temperature anomalies in the tropical Pacific are also made available. Products may be viewed at www.metoffice.gov.uk/research/seasonal. On the website, forecasts from the GloSea system may be compared with corresponding forecasts generated using output from the Euro-SIP multi-model forecast database, which currently includes forecast ensembles from the Met Office, ECMWF and Météo-France seasonal systems (Palmer *et al*., 2004). Currently Met Office products derived from Euro-SIP comprise an unweighted combination of the Met Office GloSea forecast ensemble and the ECMWF system2 seasonal ensemble.

Model calibration: GloSea forecast anomalies are expressed relative to a model climatology defined for each month of the year from a set of 15-member ensemble integrations initialised at the beginning of each month over the 15-year period 1987-2001.

8. Verification of prognostic products

Statistic	Parameter	Area	Verified by	T+24	T+72	T+120
RMS error (m)	Z 500	Northern Hemisphere	Analyses	9.81	27.06	51.59
RMS error (m)	Z 500	Southern Hemisphere	Analyses	12.50	35.54	64.72
RMS error (m)	Z 500	North America	Observations	11.11	28.00	50.90
RMS error (m)	Z 500	Europe	Observations	10.90	27.85	56.70
RMS error (m)	Z 500	Asia	Observations	14.79	26.94	45.51
RMS error (m)	Z 500	Australia/New Zealand	Observations	10.86	22.51	40.71
RMS vector wind error (ms^{-1})	W 250	Northern Hemisphere	Analyses	4.11	8.97	14.34
RMS vector wind error (ms^{-1})	W 250	Southern Hemisphere	Analyses	4.37	9.90	15.60
RMS vector wind error (ms^{-1})	W 250	North America	Observations	6.19	11.28	17.08
RMS vector wind error (ms^{-1})	W 250	Europe	Observations	5.49	10.40	17.02
RMS vector wind error (ms^{-1})	W 250	Asia	Observations	5.93	9.99	14.17
RMS vector wind error (ms^{-1})	W 250	Australia/New Zealand	Observations	6.12	9.73	14.39
RMS vector wind error (ms^{-1})	W 850	Tropics	Analyses	2.02	3.14	3.81
RMS vector wind error (ms^{-1})	W 250	Tropics	Analyses	3.49	6.28	8.08
RMS vector wind error (ms^{-1})	W 850	Tropics	Observations	4.09	4.86	5.42
RMS vector wind error (ms^{-1})	W 250	Tropics	Observations	5.68	7.30	8.73

9. Plans for the future

9.1 Computer systems

The Met Office, having successfully located to its new HQ in Exeter, is committed to simplifying its production process. This will involve many system changes to avoid duplication of data storage and product generation and allow new internet-based technologies to be utilised. This is expected to take several years to complete, but at its conclusion a more robust, but simplified production process will allow for the greater flexibility increasingly required by our customers.

Plans are underway for the replacement of both the Horace and Nimbus workstations. A unified display and production system called “SWIFT” is expected to become operational by the end of 2006.

MASS storage system

Late in 2006 it is expected to upgrade the tape library with cartridges drives which have a capacity of 500 gigabytes per cartridge.

9.2 Data assimilation

Assimilation in the global model will concentrate on consolidating the performance of the 4D-Var method at the new enhanced model resolution. The following changes are expected.

- Improved representation of physics in the Perturbation Forecast model;
- Additional use of observations, making use of the better assimilation of a-synoptic data within 4D-Var;
- Extra control variables to provide a representation of model error;
- Improvements to timings through the use of changed resolution within multiple inner loops.

Other plans for 2006 include:-

- Re-introduction - and improvement – of AIRS data processing;
- Introduction of SSMIS sounding data and use of SSMI radiances;
- Introduction of GPS data for total column water information.

9.3 Atmospheric forecast models

Short-range forecasting system

4D-Var will be implemented for the North Atlantic European model in March 2006. A package of physics improvements consistent with the proposed global package will be introduced later in 2006.

It is planned to cease running the UK 12-km mesoscale model during 2006, with all current products produced from the NAE.

Inclusion of urban heating and revisions to the soil moisture scheme are planned for the UK 4-km model.

Both the NAE and UK 4-km models will have improved vertical resolution with 60-70 levels for the NAE and 70 levels for the UK model, as well as better boundary-layer and tropospheric resolution.

Medium-range forecasting system

New physics components are planned for March 2006 aimed at improving the tropical performance of the global NWP model. These include:-

(i) Revisions to the convective parametrization to improve the detrainment process, resulting in improved modelling of vertical temperature and humidity profiles.

(ii) Revisions to marine surface transfer, including a revised thermal roughness length and using salinity to determine saturated specific humidity and hence evaporation. The main effects will be reduced evaporation over the oceans and reduction of an overactive hydrological cycle in the model.

(iii) Improving the land-use dataset by replacing the Wilson-Henderson-Sellers dataset with the International Geosphere Biosphere Programme (IGBP) dataset.

Plans for spring 2007 are to increase the vertical resolution of the global NWP model from 50 to 70 levels, with additional vertical levels in the boundary layer and free troposphere.

Monthly and seasonal forecast system

In 2006 calibrated forecast probability maps will be added to the range of seasonal forecast products, where calibration involves correction for bias in the forecast probabilities by use of past forecast performance. Output from the Météo-France seasonal system will be included in our products generated from Euro-SIP.

9.4 Ocean, wave and surge forecast models

9.4.1 Coastal ocean forecast models

In collaboration with the Proudman Oceanographic Laboratory and the Plymouth Marine Laboratory the coupled shelf seas – ecosystem model POLCOMS-ERSEM on the MRCS model grid (approximately 6 km), for the NW European shelf seas, is being assessed with a recent hindcast and pre-operational nowcast with weekly update (see www.metoffice.gov.uk/research/ncof/mrcs/index.html). It is planned to transition this model to daily operational running during 2006.

9.4.2 Global ocean forecast models

Work is continuing transitioning the FOAM ocean model system to use the Nucleus for European Modelling of the Ocean (NEMO) framework. This framework includes a new ocean model based on the French OPA code. The transition is expected to take several years to complete.

9.5 Nowcasting system

Work is underway to develop a post-processing system for the high-resolution UK model currently being developed. This post-processing system will incorporate nowcasting techniques currently used in Nimrod, to update the early parts of the forecasts. This system will eventually replace Nimrod. One element of this post-processing will be to produce site-specific forecasts, accounting for sub-grid scale orography and local land use. It is anticipated that this will eventually replace the SSFM.
Increasing use will be made of MSG data in producing cloud analyses and nowcasts of derived products.

9.6 Transport and dispersion

• Continued development of atmospheric turbulence profiles including free troposphere, boundary layer and urban effects.

• A major upgrade of the model has been undertaken which will be introduced operationally over the next year. The new model covers all ranges of dispersion, has an optional puff scheme to supplement the Lagrangian particle model, can use single site met data for short range problems, can use data from any number of nested NWP models, has a built in flow module for flow round buildings, can link to the LINCOM model to represent flow over small scale terrain and includes predictions of concentration fluctuations for short-range problems.

• Use of ensemble forecast products.

• Improved representation of atmospheric chemistry.

9.7 Tropical cyclone forecasting

Following the increase in global model resolution in December 2005, the tropical cyclone initialisation scheme will be optimised to realise the full benefits of the higher resolution model.

9.8 Stratospheric model

The stratospheric vertical levels were added to the global model in December 2005. This has brought the benefit of additional stratospheric levels in the processing of satellite temperature soundings to be realised for global weather forecasting. Currently both the global and stratospheric systems are running in parallel during a phase of intensive testing and comparison. It is anticipated that the stratosphere assimilation system will be retired in February 2006.

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