

**Progress Report on the Global Data Processing System, 2007
United Kingdom
Met Office (Exeter)**

1. Summary of highlights

1.1 Forecast models

Ocean

- 6 March 2007 Shelf Seas models upgraded to use the latest version (v.6) of the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS).
- 6 March 2007 Introduction of the European Regional Seas Ecosystem Model (ERSEM) to the Medium Resolution Continental Shelf model for UK waters, with forecast out to five days ahead.

1.2 Observations, quality control and assimilation

The following data assimilation upgrades were made to the North Atlantic-European model:-

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

- 27 November 2007 Tropical cyclone initialisation procedure changed to enable it to handle small tropical cyclones better. Areal extent of bogus data created now determined by radius of 34 knot winds rather than storm maximum sustained wind.

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 Z 9-704

B) NEC Hall 1
15 SX-6 nodes + 25 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) 80 Gigabytes

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) 3 Terabytes of on-line disk storage

B) 26 terabytes online disk storage shared between all nodes

Both systems are LAN attached to MASS (see 2.3), desktop PCs, UNIX servers and printers.

2.2 Desktop systems for forecasters

“Horace”, a Unix based HP workstation system continues to be used by the Met Office at its Operations Centre in Exeter and at the Royal Air Force Headquarters Air Command at High Wycombe (Anon., 1999; Radford, 2000). The Royal Navy also use this system at their headquarters in Northwood. The Hewlett-Packard Unix operating system was upgraded to version HP-UX11 during 2004. A version of the “Horace” software has been ported onto a Linux operating system on a desktop PC and has been deployed under contract to Bermuda, Tanzania, the British Antarctic Survey and Kosovo.

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, as well as in the Operations Centre, Exeter. 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 by a TCP/IP Wide Area Network (WAN). The systems utilise X400 message switching technologies to distribute data.

A unified display and production system named “Swift”, which will replace both the Horace and Nimbus workstations, is being developed and is scheduled to be deployed at all Met Office sites by the end of 2008.

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 held around 1,385 terabytes in December 2007 and is expected to hold 1.8 petabytes by April 2008. The current ingestion rate averages 1.5 terabytes per day.

The system comprises a 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 Storagetek 9840 cartridge drives (20 gigabyte capacity) and Storagetek 9840B cartridge drives (200 gigabyte capacity) and Storagetek T10k cartridge drives (500 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

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.

The global data assimilation system makes use of the following observation types. The counts are averages for December 2007, 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	1,300	97
	PILOT PROFILER	As TEMP, but V only	820	90
		As TEMP, but V only	6,000	50
Satellite-based vertical profiles	ATOVS	Radiances directly assimilated with channel selection dependent on surface instrument and cloudiness	4,600,000	2
	AIRS		175,000	3
	SSM/I/S		2,100,000	1
Aircraft	Manual AIREPS	T, V as reported with duplicate checking and blacklist	11,000	21
	Automated ACARS/AMDAR /ASDAR		220,000	60
Satellite atmospheric motion vectors	GOES 11, 12	High-resolution IR winds	530,000	2
	MTSAT	IR, VIS and WV winds	6,000	45
	GOES: SATOB; Meteosat 7, 8	IR, VIS and WV winds	890,000	2
	Aqua, Terra	IR, VIS and WV winds (polar)	300,000	5
Satellite-based surface winds	SSM/I-13,15	In-house 1DVAR wind-speed retrieval	2,600,000	1
	Quikscat		1,700,000	4
	ERS-2		1,000,000	4
Ground-based surface	Land SYNOP	Pressure only (processed to model surface)	76,000	80
	SHIP	Pressure and wind	15,000	90, 95
	BUOY	Pressure	56,000	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 via cable in 6-hour intervals out to T+72. Since October 1996 we have also been receiving products over the ICS 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.

A trial of GRIB data for icing, clear-air turbulence and cumulonimbus, automatically generated from the Met Office global model, has also been transmitted. A standard set of GRIB data at 1.25-degree regular grid spacing and 3-hour temporal resolution was also generated for trial evaluation during 2007.

Products received from Météo-France, Deutscher Wetterdienst and ECMWF (including Ensemble Prediction System forecasts) are used internally for national forecasting.

4. 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 (4D-Var)
4. Regional atmospheric forecast model (NAE)
5. Mesoscale atmospheric data assimilation system (4D-Var)
6. Mesoscale (4-km) atmospheric forecast model
7. Mesoscale (1.5-km) relocatable atmospheric forecast model (run on demand)
8. Transport and dispersion model
9. Nowcasting model
10. Global wave hindcast and assimilation/forecast system
11. Regional wave hindcast and forecast system
12. Mesoscale wave hindcast and forecast system
13. Mesoscale models for sea surge
14. Global ocean model
15. Regional ocean models
16. Nested ocean models
17. Mesoscale Shelf-seas model
18. Nested Shelf-seas model
19. Global single-column (site-specific) model
20. Mesoscale single-column (site-specific) model.
21. Global atmospheric ensemble forecast model (24 members)
22. Regional atmospheric ensemble forecast model (24 members)

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.

Data input system

Fully automated.

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.

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 (Lorenz 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).

4.1 System run schedule and forecast ranges

Run	Model	Forecast range	Forecast cut-off	Boundary values	Product available
QU18	Global atmospheric update	T+9	00:15		01:00
QZ18	Regional atmospheric update	T+3	00:15	QG18	00:50
QN00	Regional FOAM	T+120	00:30	QG12	01:00
QV00	Regional FOAM	T+72	01:20	QG12	01:50
QY00	Regional atmospheric	T+48*	01:30	QG18	02:25
SY00	Regional single column		02:05	QY00	02:50
QD00	Regional marine	T+48	02:35	QY00	03:05
Q400	Local 4-km atmospheric update	T+3	02:40	QY00	02:55
QG00	Global atmospheric	T+144*	02:45		04:00
SP00	Preliminary single column	T+36	03:20	QG00	03:35
SG00	Global single column	T+144	03:40	QG00	04:45
QW00	Global marine	T+144	04:05	QG00	05:00
EG00	Global ensemble	T+72	04:10	QG00	06:35
Q403	Local 4-km atmospheric	T+36	04:20	QY00	05:05

Run	Model	Forecast range	Forecast cut-off	Boundary values	Product available
QO00	Global FOAM	T+144	04:20	QG00	05:40
QU00	Global atmospheric update	T+9	06:15		07:05
QZ00	Regional atmospheric update	T+3	06:15	QG00	06:50
QQ00	Regional Shelf-seas	T+48	06:25	QG00	07:50
Q503	Local 1.5-km atmospheric	T+15	07:00	Q403	07:40
QY06	Regional atmospheric	T+48*	07:30	QG00	08:25
SY06	Regional single column		08:05	QY06	08:50
EY06	Regional ensemble	T+52	08:35	QY06	11:10
QD06	Regional marine	T+48	08:35	QY06	09:05
Q406	Local 4-km atmospheric update	T+3	08:40	QY06	08:55
QG06	Global atmospheric	T+48	08:45		09:35
Q409	Local 4-km atmospheric	T+36	09:05	QY06	09:50
SP06	Preliminary single column	T+36	09:20	QG06	09:35
QL00	Regional shelf-seas	T+120	09:40	QG00	10:00
QU06	Global atmospheric update	T+9	12:15		13:10
QZ06	Regional atmospheric update	T+3	12:15	QG06	12:50
QY12	Regional atmospheric	T+48*	13:30	QG06	14:25
SY12	Regional single column		14:05	QY12	14:50
QD12	Regional marine	T+48	14:35	QY12	15:05
Q412	Local 4-km atmospheric update	T+3	14:40	QY12	14:55
QG12	Global atmospheric	T+144*	14:45		16:00
SP12	Preliminary single column	T+36	15:20	QG12	15:35
SG12	Global single column	T+144	15:40	QG12	16:45
QW12	Global marine	T+144	16:05	QG12	17:00
EG12	Global ensemble	T+72	17:10	QG12	19:35
Q415	Local 4-km atmospheric	T+36	16:20	QY12	17:05
Q515	Local 1.5-km atmospheric	T+15	18:15	Q415	18:55
QU12	Global atmospheric update	T+9	18:15		19:00
QZ12	Regional atmospheric update	T+3	18:15	QG12	18:55
QY18	Regional atmospheric	T+48*	19:30	QG12	20:25
SY18	Regional single column		20:05	QY18	20:50
EY18	Regional ensemble	T+52	20:35	QY18	23:10
QD18	Regional marine	T+48	20:35	QY18	21:05
Q418	Local 4-km atmospheric update	T+3	20:40	QY18	20:55
QG18	Global atmospheric	T+48	20:45		21:35
SP18	Preliminary single column	T+36	21:20	QY18	21:35
Q421	Local 4-km atmospheric	T+36	22:20	QY18	23:05

N.B. Models marked * are run to T+60 and T+168 respectively for backup purposes only.

4.2 Medium-range forecasting system (2-10 days)

4.2.1 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 4.2.2), but resolution is 1.111° latitude and 1.667° longitude

Vertical grid Same levels as forecast model (see 4.2.2)

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 4.2.2)
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 Thépaut (2001). The initialised increments are inserted directly at T-3.

4.2.2 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: 0.556° latitude and 0.833° longitude. Arakawa 'C'-grid staggering of variables.
Vertical grid	50 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 Helmholtz 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 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 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.

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.

4.2.3 Operationally available 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.

4.2.4 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 4.2.5). 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.

4.2.5 Ensemble prediction system

The ECMWF Ensemble Prediction System (EPS) is utilised for medium-range forecasting. In addition forecasters now have access to experimental global 15-day ensemble forecasts from the Met Office ensemble prediction system (MOGREPS). 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. Product generation from the EPS is currently being upgraded to exploit the new ECMWF VAREPS system to provide forecast guidance to 15 days.

In addition Site-specific probability forecasts of temperature, wind speed and precipitation are stored in our site-specific database: FSSSI (see 4.2.4). Forecasts of cloud cover and sunshine are available for a limited set of UK sites. A Kalman Filter MOS (Model Output

Statistics system) 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 the Kalman Filter MOS 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.

As a major part of our THORPEX research programme, we have started regular 15-day ensemble forecasts using MOGREPS (Met Office Global and Regional Ensemble Prediction System). This is an extended version of the global component of MOGREPS, described in paragraph 4.3.5. The 24-member ensemble is currently run twice a day (0000 and 1200 UTC), using a global model with a nominal grid length of 90 km. Initial condition perturbations are provided using an ETKF (Ensemble Transform Kalman Filter) method. The model also includes stochastic physics schemes to account for the effect of model errors on forecast uncertainty.

Experimental products from the MOGREPS 15-day forecasts are made available to forecasters on an internal web-based system. These products are largely based on those originally developed for the MOGREPS short-range forecasts, including probability charts, spaghetti diagrams and postage stamps. The forecasts are also processed by an automatic system to characterise synoptic features and write those details to a cyclone database. By combining information in the cyclone database with tracking software, we have built a web-based system in which forecasters can visualise how cyclones are forecast to develop by the different ensemble members.

Output from the medium-range ensemble is also being written to the TIGGE (THORPEX Interactive Grand Global Ensemble) database. It is expected that the TIGGE database will become open to the scientific research community during 2007. The TIGGE database will include a standard set of ensemble forecast output from several operational numerical weather prediction centres. It will be an invaluable resource for research into ensemble prediction, especially the benefits of using multi-model ensemble techniques.

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

4.3.1 Data assimilation, objective analysis and initialization

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 4.2.1), but includes aerosol content
Analysis domain	As model integration domain (see 4.4.2)
Horizontal grid	Half model resolution (see 4.4.2)
Vertical grid	As model levels
Assimilation method	3D variational analysis of increments for 'conventional' data (Lorenz <i>et al.</i> , 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 NAE forecast model (see 4.3.2)

Assimilation cycle	Increments from 'conventional' data are introduced gradually into the model using an Incremental Analysis Update (Bloom <i>et al.</i> , 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 <i>et al.</i> , 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.

4.3.2 Forecast model

The NAE model is identical to the global 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 70° N to 30° N, 70° W to 50° E, but distorted due to rotated grid).
Horizontal grid	Spherical rotated latitude-longitude with pole at 37.5° N, 177.5° E. Resolution: 0.111°.
Vertical grid	38 levels and 38-km 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 1-km (based on 100-m) data.
Boundary values	Specified from global forecast model with the previous data time (T-6, i.e. forecasts from 1800, 0000, 0600 and 1200 UTC).

Physics parametrizations:-

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

4.3.3 Operationally available NWP products

4.3.4 Operational techniques for application of NWP products

4.3.5 Short-range ensemble prediction system

A new short-range Ensemble Prediction System based on the Unified Model successfully completed its initial trials during 2006 and is planned to become fully operational during 2007. MOGREPS (Met Office Global and Regional Ensemble Prediction System) provides a 24-member regional ensemble covering the North Atlantic and Europe (NAE domain) with a grid-length of 24 km, running twice daily (0600 and 1800 UTC) to 36 hours ahead. A global ensemble with grid-length of 90-km runs twice daily (0000 and 1200 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. Three stochastic physics schemes are employed to account for model error in assessing forecast uncertainty. Products are provided to forecasters in real-time on an

internal web-based system. Chart-based products include ensemble mean and spread, probabilities for a wide variety of variables and thresholds including many surface parameters relevant to the short-range forecast, spaghetti diagrams, postage stamp charts and clustering. Some feature-based products provide cyclone tracking and probabilities of feature-specific diagnostics such as cyclone central pressure and maximum windspeed. Site-specific forecast products are generated through the FSSSI database and include ensemble meteograms, plumes and wind-roses.

Site-specific ensemble forecasts of wind and associated parameters from several centres around Europe (MOGREPS, Météo-France, met.no in Norway, DWD, ARPA-SIM in Italy and ECMWF) are processed to provide a wind-storm warning service up to 5 days ahead for the EU under the Eurorisk PREVIEW Windstorms project. This system is currently under pre-operational trials.

4.4 Nowcasting and very short-range forecasting systems (0-6 hours)

4.4.1 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° N to 64° N, 12° W to 13° W, and the European domain extending from 30° W to 43° E at 60° N and from 10° W to 25° E at 35° 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 <i>et al.</i> , 1994).

4.4.2.1 Very short-range forecast system: UK 4-km model

Data assimilation

Data assimilation for the UK 4-km model is similar to that for the NAE model described in 4.3.1, except:-

Data	A daily analysis of soil moisture content is performed from 'data' produced by the Nimrod soil state diagnostic model.
------	--

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 62° N to 48° N, 11° W to 5° E).
Horizontal grid	Spherical rotated latitude-longitude with pole at 37.5° N, 177.5° E. Resolution: 0.036°.
Vertical grid	38 levels and 38-km 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 inhibit 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).

4.5 Specialized numerical models

4.5.1 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	Developed from the Analysis Correction scheme of Lorenc <i>et al.</i> (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 <i>et al.</i> , 2000).
Surface fluxes	From the global NWP model, 6-hourly

4.5.2 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 <i>et al.</i> , 1990) is a variant of the analysis-correction scheme of Lorenc <i>et al.</i> (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. No data are now 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 <i>et al.</i> , 1981); white-capping dissipation (Komen <i>et al.</i> , 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).

4.5.3 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 thermodynamic/simple advection sea-ice model.
Integration domain	(1) Atlantic/Arctic; (2) North Atlantic; (3) Mediterranean; (4) Indian Ocean; (5) Antarctic.
Horizontal grid	(1) 1/3° x 1/3°. Rotated grid with pole at 17° N, 56° E; (2) 1/9° x 1/9°. Rotated grid with pole at 42° N, 160° E; (3) 1/9° x 1/9°; (4) 1/3° x 1/3°; (5) 1/4° x 1/4°. Rotated grid with pole at 5° N, 75° 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 <i>et al.</i> (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.

4.5.4 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 67.7° 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.

4.5.5 Wave hindcast and forecasting system: local wave model

The local 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.

4.5.6 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.

4.5.7 Nested coastal ocean models

Model type	POLCOMS: Baroclinic piecewise parabolic advection scheme, Mellor Yamada turbulent mixing; hybrid co-ordinate
Integration domain (1)	NW European shelf seas Medium Resolution Continental Shelf model (MRCS), with western boundary at approximately the 200m depth contour
Integration domain (2)	Irish Sea
Grid (1)	Spherical latitude-longitude from 48° N to 62° N and from 12°W to 13°E. Resolution 1/10° latitude, 1/15° longitude
Grid (2)	Spherical latitude-longitude from 51° N to 56° N and from 7° W to 2.7° W. Resolution 1/60° latitude, 1/40° 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 domain (1)) or from MRCS model (for domain (2)); 3) River inflows – daily climatology, data provided by the Environment Agency
Surface classification	No sea Ice, wetting or drying
Ecosystem model	The POLCOMS MRCS model (domain (1)) has been coupled with a generic ecosystem model, ERSEM-2004 (Blackford <i>et al.</i> , 2004). The ERSEM code is driven by temperature, salinity and diffusivity from the physical model. ERSEM has 100 biological, pelagic and benthic state variables with multiple classes of phytoplankton and zooplankton. The model also considers bacteria, dissolved and particulate organic matter and nutrients.

4.5.8 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.

4.5.9 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 and changes made in 2007 may be found in Heming *et al.* (1995) and Heming (2008).

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.

4.5.10 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. The model can also be used to compute three-dimensional trajectories.

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 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.

4.6 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 (Terry *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 62 levels in the vertical. The model is currently run once each week from initial conditions at 00GMT Thursday.

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. Forecast categories are defined relative to this 60-member realisation of the model climatology (5 members x 12 years).

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, forecasts for European weather regimes, and detailed forecasts for the 10 UK climate districts. Probability products are provided in the form of 1) global probability maps for tercile and outer-quintile categories, 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 both these formats the forecast variables are temperature, precipitation and wind speed. Population-weighted probability products are also generated. For the 10 UK climate districts probabilities are predicted for quintile categories for temperature and rainfall and for tercile categories for sunshine. As well as these probabilistic forecasts, for the UK a deterministic forecast is produced 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.

4.7 Long-range forecasts

Seasonal forecasts to 6 months ahead are generated each month using the Met Office's 41-member 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 ECMWF's System 3 seasonal prediction model as part of a developing European multi-model seasonal prediction capability (Palmer *et al.*, 2004), known as EUROSIP. Further details of the GloSea system are provided below. A performance assessment is provided in 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 model 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, and 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 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 40 perturbed ocean states for initialising the forecast 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.

Forecast products

GloSea forecasts are initialised from the first day of each month and run out to 6 months ahead. A range of forecast products are made available to NMSs, Regional Climate Outlook Forums, UK government agencies, commercial companies and the public. 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 (below the 20th and above the 80th percentile, respectively).

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 may be viewed together with the forecast maps. Forecast products for monthly-mean sea surface temperature anomalies in the tropical Pacific are also made available, as well global maps of ensemble mean predictions for temperature, precipitation, sea-level pressure, 500hPa height, 850hPa and sea-surface temperature. Products may be viewed at <http://www.metoffice.gov.uk/research/seasonal>. On the website, forecasts from the GloSea system may be compared with corresponding forecasts from a multi-model system comprising an unweighted combination of the Met Office GloSea forecast ensemble and the ECMWF System 3 seasonal ensemble. The products made available comply with the minimum list, specified by WMO, required from

Global Producing Centres (GPCs) for Long-range forecasts (the Met Office is one of nine centres designated as GPCs by WMO).

This year, for the first time, a prediction was issued for the number of tropical storms in the July to November 2007 period over the Atlantic basin. The prediction gave good guidance, with the observed number of 12 storms falling within the predicted range of 7 to 13.

A number of supporting prediction tools have been developed this year. These include an analysis of the historical observed influence of El Niño and la niña events on European seasonal climate stratified for each season (winter, spring, summer and autumn) and a weather-regime analysis of the GloSea system output. Both these supporting tools are routinely used to guide forecaster interpretation of the GloSea model predictions.

Operational seasonal forecast statements for temperature and precipitation prospects over the UK/Europe region, previously limited to the winter and summer seasons, have for the first time this year also been provided for the spring and autumn seasons.

The main prediction tools employed are the Met Office dynamical prediction model (GloSea) and, for the winter season, a statistical prediction method for the North Atlantic Oscillation (NAO) (Rodwell and Folland, 2002). A case study using a range of models (Scaife and Knight, 2008) showed that both North Atlantic ocean conditions and the state of the Arctic stratosphere promoted the cold European winter of 2005-6; Scaife and Knight (2008) argue that these effects influence European winter climate more generally. Also, insights from papers by Toniazzo and Scaife (2006) and Fereday *et al.* (2008) on the influence of ENSO are used to guide decisions on winter forecasts. The forecast for winter 2007/8 had to consider the influence of a strong La Nina. The consolidated forecast considering all these inputs predicted an enhanced chance of overall positive North Atlantic Oscillation signal for the winter, more evident in January and February than in December. This, and the outcomes specifically predicted as most likely for the UK (above average temperatures, but less mild than last year, and average or above average rainfall) provided good guidance.

The rainfall forecast for summer 2007 was consistent with observation only for the north of the UK. Even here, however, the tercile-category precision appropriate given current limited forecast skill (below, near, above average) was insufficient to signal the extreme nature of the observed rainfall, which was the highest since 1914 in many regions. This year research has been initiated to assess potential for forecast products indicating the risk of more extreme events. Met Office European/United Kingdom forecasts may be viewed at http://www.metoffice.gov.uk/weather/uk/uk_forecast_weather.html.

As in previous years, output from the dynamical prediction system has been used to contribute to WMO El Niño/la niña outlook statements. The GloSea ensemble provided good guidance for the onset and strengthening of La Niña conditions through the latter half of 2007. Regionally specific seasonal precipitation forecasts based on combining statistical and dynamical forecasts were issued for tropical NW Africa, East Africa and NE Brazil - regions with high climate vulnerability and for which seasonal forecast skill is relatively high. This year a new format for seasonal forecast products has been investigated which combines observational information on recent climate anomalies with predicted information on the expected evolution of the anomalies. The new format is designed to highlight regions in which existing adverse anomalies are likely to be exacerbated or alleviated, or where new adverse anomalies may develop. A prototype product has been developed for European temperature.

Research into decadal forecasting has reached a milestone with the publication of Smith *et al.* (2007) which describes the current methodology. It particularly shows that the incorporation of real initial conditions provides extra skill over the full 10 year forecast period in a 20 year series of hindcasts. The paper also predicts a global warming of $0.30^{\circ}\text{C}\pm 0.21^{\circ}\text{C}$ between 2004 and 2014, though with little warming until 2008.

Decadal-range prediction products for the UK have been developed as aids for business planning. Because of climate change, climatological temperature averages of historical observations, widely used for planning purposes in business and other sectors, are becoming unrepresentative baselines for planning under 'present day' climate. With the expected continued warming, conventional historical climate averages are even less appropriate for use as planning baselines for the next 10 years. Using the Met Office's decadal prediction system (DePreSys, Smith *et al.*, 2007), new climatological averages have been developed that take account of both past and predicted climate change, including changes to the seasonal and diurnal cycles, and provide up-to-date planning baselines specific to the year being planned (up to 2018). The detailed format of the climatology products has been designed through discussions with a 'focus' group of users from the energy industry.

Work has also been done to understand the significant effects of sampling errors (due to limited sampling of both the forecast probability distribution function and the number of historical states) on typical information contained in seasonal forecasts. Alternative methods of reducing sampling errors have been investigated, including the adoption of appropriate statistical models to parameterise forecast probability distribution functions and the spatial and temporal aggregations of predictions. Results have been submitted for publication to *Monthly Weather Review* (Cusack and Arribas, 2008).

Cusack and Arribas (2008) describe general measures of usefulness of forecasts to end-users. In the future, system development will be explicitly linked to the usefulness of forecasts to end-users by these new assessment measures.

5. Verification of prognostic products

Statistic	Level	Area	Verified vs.	T+24	T+72	T+120
RMS height error (m)	500 hPa	Northern Hemisphere	Analyses	8.08	24.32	47.35
RMS height error (m)	500 hPa	Southern Hemisphere	Analyses	10.21	30.80	58.17
RMS height error (m)	500 hPa	North America	Observations	10.83	26.40	48.85
RMS height error (m)	500 hPa	Europe	Observations	10.97	26.16	52.94
RMS height error (m)	500 hPa	Asia	Observations	13.60	23.90	41.57
RMS height error (m)	500 hPa	Australia/NZ	Observations	10.41	20.75	36.30
RMS vector wind error (ms ⁻¹)	250 hPa	Northern Hemisphere	Analyses	3.75	8.44	13.59
RMS vector wind error (ms ⁻¹)	250 hPa	Southern Hemisphere	Analyses	3.94	9.14	14.70
RMS vector wind error (ms ⁻¹)	250 hPa	North America	Observations	5.97	10.92	16.64
RMS vector wind error (ms ⁻¹)	250 hPa	Europe	Observations	5.46	10.22	16.60
RMS vector wind error (ms ⁻¹)	250 hPa	Asia	Observations	5.69	9.48	13.53
RMS vector wind error (ms ⁻¹)	250 hPa	Australia/NZ	Observations	5.80	9.07	12.93
RMS vector wind error (ms ⁻¹)	850 hPa	Tropics	Analyses	1.96	2.98	3.61
RMS vector wind error (ms ⁻¹)	850 hPa	Tropics	Analyses	3.43	6.03	7.64
RMS vector wind error (ms ⁻¹)	850 hPa	Tropics	Observations	3.80	4.74	4.97
RMS vector wind error (ms ⁻¹)	250 hPa	Tropics	Observations	5.51	7.14	8.43

6. Plans for the future

6.1 Computer systems

Plans are under way to replace the Supercomputer in 2009 with one that will initially be 6 times more powerful than the current supercomputer. Alongside that more advanced plans are under way to replace the MASS system with one able to handle the additional data produced by the replacement supercomputer.

Plans are in place for the replacement of both the Horace and Nimbus workstations. A unified display and production system called "Swift" is expected to become operational by mid-2008.

6.2 Planned research activities in numerical weather prediction, nowcasting and long-range forecasting

6.2.1 Data assimilation

Assimilation in the global model will concentrate on introducing an enhanced model vertical resolution (to 70 levels). Later possible changes:-

- Further improved representation of physics in the Perturbation Forecast model.
- Additional use of observations, making further use of 4D-Var.
- Improvements in performance and timings through the combination of assimilation in main and update cycles.

6.2.2 Atmospheric forecast models

Short-range forecasting system

Both the NAE and UK 4-km models will have improved vertical resolution. The NAE will have the same 70 levels as proposed for the global model. A different 70-level configuration will be used in the UK model. Both models will have better boundary-layer and tropospheric resolution.

Medium-range forecasting system

Plans for 2008 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.

Long-range forecasts

From March 2008 monthly forecasts will be based on the ECMWF variable resolution Ensemble Prediction System (VarEPS).

The development of the new version of the seasonal forecasting system, GloSea4, has been ongoing in the past year, in preparation for operations in April 2009. In common with previous system versions and other operational centres, the atmosphere and ocean initial conditions are from independent sources. This leads to a period of coupling adjustment between the two climate system components that can remove some of the predictable signal in forecasts. A new scheme for coupling of the atmosphere and ocean initial conditions is being developed to minimise the loss of initial condition predictability. The forecast model will be based on the third version of the Met Office Hadley Centre Global Environmental Model, HadGEM3, currently being developed for climate prediction on seasonal to centennial scales. Research in post-processing has led to the development of methods to extract significantly more information from forecasts than with standard techniques. This enables the use of smaller forecast and hindcast ensembles to obtain similar magnitudes of sampling errors. These new methods allow much more frequent calculation of hindcast sets for post-processing purposes, thus allowing a more rapid development cycle for seasonal forecast systems.

Forecasts of temperature over Europe derived from the statistical North Atlantic Oscillation method have been adapted to allow for global warming and the influence of El Nino. Possible extra skill in simulating winter atmospheric circulation using a version of HadGEM with many more levels in the stratosphere is being investigated.

Research continues on the concept of the Summer North Atlantic Oscillation (SNAO) to identify mechanisms that influence its variability and predictability. A paper has been submitted for publication (Folland *et al.*, 2008). A key result is that the probability of the

SNAO being in its positive phase (anticyclonic warm and dry over North West Europe) increases quite strongly under enhanced CO₂ concentrations.

Decadal forecasting uses the HadCM3 model and initialisation of decadal forecasts is done differently from seasonal forecasts. Over the next few years the model to be used and whether seasonal and decadal forecasts should be initialised in the same way will be carefully investigated.

6.2.3 Ocean, wave and surge forecast models

Ocean models: Introduction of NEMO

Work is underway to transition the open ocean FOAM system to use the Nucleus for European Modelling of the Ocean (NEMO) ocean model. The transition of the FOAM system is expected to complete in 2008 with the implementation of a 1/4 degree, 50-level global configuration, with nested 1/12 degree basin scale configurations. This will be followed by work to transition the shelf seas models to use the same NEMO ocean model code. Work is underway to develop the NEMO model code for application to shelf seas modelling.

Wave forecast models

The wave modelling system will be transitioned to use the WaveWatch III code during 2008, with the operational implementation expected towards the end of the year. The existing global wave model will be replaced by a WaveWatch III configuration with the same spatial resolution (~60 km), but with increased frequency and directional resolution. The current regional and local configurations will be replaced by a single North Atlantic European WaveWatch III configuration with ~12-km grid resolution.

6.2.4 Nowcasting system

Increasing use will be made of Meteosat-8 data in producing cloud analyses and nowcasts of derived products.

7. References

Anon., 1999: Horace: a visualisation tool for professional meteorologists. *NWP Gazette*, December 1999, 8-9

Bell, M. J., Forbes, R. M. and Hines, A., 2000: Assessment of the FOAM global data assimilation system for real-time operational ocean forecasting. *J. Marine Sys.*, **25** (1): 1-22

Blackford J. C., Allen J. I. and Gilbert, F. J., 2004: Ecosystem dynamics at six contrasting sites: a generic modelling study. *J. Marine Sys.*, **52**: 191-215

Bloom, S. C., Takaka, L. L., Da Silva, A. M. and Ledvina, D., 1996: Data assimilation using incremental analysis updates. *Mon. Weath. Rev.*, **124**: 1256-1271

Clough, S. A., Kenizys, F. X. and Davies, R. W., 1989: Line shape and the water vapor continuum. *Atmos. Res.*, **23**: 229-241

Cooper, M. and Haines, K., 1996, Data assimilation with water property conservation. *J. Phys. Oceanogr.*, **101**: 1059-1077

Cox, P., Best, M., Betts, R. and Essery, R., 2001: Improved representation of land-surface patchiness in the mesoscale model. *NWP Gazette*, March 2001, 8-10

Cusack, S. and Arribas, A., 2008: Assessing the usefulness of probabilistic forecasts. *Mon. Wea. Rev.* (in press)

- Cusack, S., Edwards, J. M. and Crowther, J. M., 1999: Investigating k distribution methods for parameterizing gaseous absorption in the Hadley Centre Climate Model. *J. Geophys. Res. (Atmos.)*, **104D**: 2051-2057
- Edwards, J. M. and Slingo, A., 1996: Studies with a flexible new radiation code, Part I. Choosing a configuration for a large-scale model. *Q. J. R. Meteorol. Soc.*, **122**: 689-719
- English, S. J., Renshaw, R. J., Dibben, P. C., Smith, A. J., Rayer, P. J., Poulsen, C., Saunders, F. W. and Eyre, J. R., 2000: A comparison of the impact of TOVS and ATOVS satellite sounding data on the accuracy of numerical weather forecasts. *Q. J. R. Meteorol. Soc.*, **126**: 2911-2932
- Fereday, D. R., Knight, J. R., Scaife, A. A., Folland, C. K. and Philipp, A., 2008: Cluster analysis of North Atlantic circulation types. *J. Clim.* (in press)
- Folland, C. K., Knight, J., Linderholm, H., Fereday, D., Ineson, S. and Hurrell, J., 2008: The summer North Atlantic Oscillation: past, present and future. *J. Clim.* (in press)
- Fritsch, J. M. and Chappell, C. F., 1980: Numerical prediction of convectively driven mesoscale pressure systems. Part I. Convective parameterization. Part II. Mesoscale model. *J. Atmos. Sci.*, **37**: 1722-1762
- Gauthier, P. and Thepaut, J.-N., 2001: Impact of the digital filter as a weak constraint in the preoperational 4DVAR assimilation system of Météo-France. *Mon. Weath. Rev.*, **129**: 2089-2102
- Geleyn, J.-F. and Hollingsworth, A., 1979: An economical analytical method for the computation of the interaction between scattering and line absorption of radiation. *Contrib. Atmos. Phys.*, **52**: 1-16
- Gordon, C., Cooper, C., Senior, C. A., Banks, H., Gregory, J. M., Johns, T. C., Mitchell, J. F. B. and Wood, R. A., 2000: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Clim. Dyn.*, **16**: 147-168
- Graham, R. J., Gordon, M., McLean, P. J., Ineson, S., Huddleston, M. R., Davey, M. K., Brookshaw, A. and Barnes, R. T. H., 2005: A performance comparison of coupled and uncoupled versions of the Met Office seasonal prediction general circulation model. *Tellus*, **57A**: 320-339
- Grant, A. L. M., 2001: Cloud-base fluxes in the cumulus-capped boundary layer. *Q. J. R. Meteorol. Soc.*, **127**: 407-421
- Grant, A. L. M. and Brown, A. R., 1999: A similarity hypothesis for shallow-cumulus transports. *Q. J. R. Meteorol. Soc.*, **125**: 1913-1936
- Hamill, T. M. and Colucci, S. J., 1997: Verification of Eta-RSM short-range ensemble forecasts. *Mon. Weath. Rev.*, **125**: 1312-1327
- Heming, J.T., 2008: Tropical cyclone initialisation in the Met Office global model: Is it still necessary and can it be improved? *AMS 28th Conf. Hurricanes Tropical Meteorol.* (Orlando, USA)

- Heming, J. T., Chan, J. C. L. and Radford, A. M., 1995: A new scheme for the initialisation of tropical cyclones in the UK Meteorological Office global model. *Meteorol. Appl.*, **2**: 171-184
- Holt, M. W., 2002: Real-time forecast modelling for the NW European shelf seas. *Proc. 2nd Int. Conf. EuroGOOS, 11-13 March 1999, Rome, Italy*: 69-76
- Jones, C. D. and Macpherson, B., 1997: A latent-heat nudging scheme for the assimilation of precipitation data into an operational mesoscale model. *Meteorol. Appl.*, **4**: 269-277
- Kitchen, M., Brown, R. and Davies, A. G., 1994: Real-time correction of weather radar data for the effects of bright band, range and orographic growth in widespread precipitation. *Q. J. R. Meteorol. Soc.*, **120**: 1231-1254
- Komen, G., Hasselmann, K. and Hasselmann, S., 1984: On the existence of a fully developed windsea spectrum. *J. Phys. Ocean.*, **14**: 1272-1285
- Kristjansson, J. E., Edwards, J.M. and Mitchell, D.L., 2000: Impact of a new scheme for optical properties of ice crystals on climates of two GCMs. *J. Geophys. Res. (Atmos.)*, **105D**: 10063-10079
- Lock, A. P., Brown, A. R., Bush, M. R., Martin, G. M. and Smith, R. N. B., 2000: A new boundary-layer mixing scheme, Part I: Scheme description and single-column tests. *Mon. Weath. Rev.*, **32**, 3187-3199
- Lorenc, A. C. and Hammon, O., 1988: Objective quality control of observations using Bayesian methods. Theory and a practical implementation. *Q. J. R. Meteorol. Soc.*, **114**, 515-543
- Lorenc, A. C., Bell, R. S. and Macpherson, B., 1991: The Meteorological Office analysis correction data assimilation scheme. *Q. J. R. Meteorol. Soc.*, **117**: 59-89
- Lorenc, A. C., Ballard, S. P., Bell, R. S., Ingleby, N. B., Andrews, P. L. F., Barker, D. M., Bray, J. R., Clayton, A. M., Dalby, T., Li, D., Payne, T. J. and Saunders, F. W., 2000: The Met. Office global 3-Dimensional Variational Data Assimilation. *Q. J. R. Meteorol. Soc.*, **126**: 2991-3012
- McHugh, B., Moores, B. and Hayes, P., 2000: The Nimbus family of forecasting systems. *NWP Gazette*, December 2000, 3-5
- Macpherson, B., Wright, B. J., Hand, W. H. and Maycock, A. J., 1996: The impact of MOPS moisture data in the UK Meteorological Office Mesoscale Data Assimilation Scheme. *Mon. Weath. Rev.*, **124**: 1746-1766
- Palmer, T. N., Davey, M., Graham, R. and others, 2004: Development of a European Multi-Model Ensemble System for Seasonal to Inter-Annual Prediction (DEMETER). *Bull. Amer. Met. Soc.*, **85**: 853-872
- Phillips, O. M., 1958: The equilibrium range in the spectrum of wind-generated waves. *J. Fluid Mech.*, **4**: 426-434
- Radford, A., 2000: Horace – recent developments. *NWP Gazette*, September 2000, 6-7
- Rodwell, M. J. and Folland, C. K., 2002: Atlantic air-sea interaction and seasonal predictability. *Q. J. R. Meteorol. Soc.*, **128**: 1413-1443

- Scaife, A. A. and Knight, J. R., 2008: Ensemble simulations of the cold European winter of 2005-6, submitted to *Q. J. R. Meteorol. Soc.*
- Smith, D., Cusack, S., Colman, A., Folland, C.K., Harris G. R. and Murphy, J., 2007: Improved surface temperature prediction for the coming decade from a global climate model. *Science*, **317**: 796-799
- Smith, R. N. B., 1990: A scheme for predicting layer clouds and their water contents in a general circulation model. *Q. J. R. Meteorol. Soc.*, **116**: 435-460
- Snyder, R. L., Dobson, F. W., Elliot, J. A. and Long, R. B., 1981: Array measurements of atmospheric pressure fluctuations above surface gravity waves. *J. Fluid Mech.*, **102**: 1-60
- Stratton, R. A., Harrison, D. L. and Bromley, R. A., 1990: The assimilation of altimeter observations in a global wave model. *AMS 5th Conf. Satel. Meteorol. Ocean.*, London: 108-109
- Sea Wave Modelling Project (SWAMP), 1985: An intercomparison study of wind wave prediction models, Part I: Principal results and conclusions. *Ocean wave modelling*. Plenum Press
- Terray, L., Sevault, E., Guilyardi, E. and Thual, O., 1995: The OASIS coupler user guide, version 2.0, *CERFACS Tech. Rep. TR/CMGC/95-46*
- Thomas, J. P., 1988: Retrieval of energy spectra from measured data for assimilation into a wave model. *Q. J. R. Meteorol. Soc.*, **114**: 781-800
- Toniazzo, T. and Scaife, A. A., 2006: The effects of ENSO on North Atlantic climate. *Geophys. Res. Lett.*, **33**: L24704. doi:10.1029/2006GL027881
- Vitart, F., 2003: Monthly forecasting system. *ECMWF Tech. Memo. No. 424*. Reading
- Webster, S., Brown, A.R., Cameron, D. R. and Jones, C. P. 2003: Improvements to the representation of orography in the Met Office Unified Model. *Q. J. R. Meteorol. Soc.*, **129**: 1989-2010
- Wilson, D. R. and Ballard, S. P., 1999: A microphysically based precipitation scheme for the UK Meteorological Office Unified Model. *Q. J. R. Meteorol. Soc.*, **125**, 1607-1636
- Wolff, J. O., Maier-Raimer, E. and Legutke, S., 1997: *The Hamburg Ocean Primitive Equation Model*. Tech. Rep., **13**. Deutsches Klimarechenzentrum, Hamburg