Progress Report on the Global Data Processing System, 2003
United Kingdom
Met Office (Exeter)

1. Summary of highlights

1.1 Forecast models

Atmosphere

In March 2003 a new global model cycle (G31) was introduced into operations. The main change was an additional constraint to the diagnosis of shallow convection requiring downward motion at top of BL. This reduced the frequency of shallow convection in favour of deep convection in equatorial regions and helped alleviate grid-point storms. In addition, subtropical cloud cover was reduced to give better agreement with ISCCP (International Satellite Cloud Climatology Project) cloud and improve top-of-the-atmosphere radiation balance compared with ERBE (Earth Radiation Budget Experiment) figures. Other minor changes in this cycle were implemented to improve numerical stability and included targeted diffusion of moisture, designed to operate in circumstances of the extreme vertical velocities typical of a grid point storm.

In October 2003 a major upgrade was implemented in the stratospheric model. This change, known as New Dynamics, introduced a non-hydrostatic dynamical core, with height as the vertical coordinate. This change had previously been implemented in most other forecast model configurations during 2002.

Ocean

A high-resolution nested shelf-seas model was introduced during March 2003, covering the Irish Sea.

The wave model swell dissipation coefficient was re-set from 14th October 2003, inline with theoretical estimates.

The data assimilation component of the FOAM Global and regional ocean model systems was upgraded on 28th October 2003. The upgrade included a number of significant enhancements to the assimilation scheme, and implemented the assimilation of Argo salinity data.

Nowcasting system

Changes were made to the Nimrod short-range forecasting system as follows:

5 March Soil moisture scheme changed to use maximum root depth

21 March Cloud-top height scheme revised to improve the modelling of inversions

23 July Improved wind forecast over high ground introduced

5 August Towering convection forecast introduced for aviation

11 November Sub-surface runoff added to soil moisture scheme

4 December Radar data correction frequency increased from 15 to 5 minutes.

1.2 Observations, quality control and assimilation

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

18 March AMSU satellite data and Meteosat-6 rapid scan winds were introduced. The assimilation of radar rainfall data by latent heat nudging was retuned, giving less weight to observations.

The following data assimilation upgrade was made to the global model.

8 July Replacement of GMS satellite winds by GOES-9 wind data.

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 Z800 – 0A2
IBM Z800 – 001

B) Cray T3Ea (880 PEs)
Cray T3Eb (640 PEs)
(PE – processor element)

2.1.2 Main storage

A) 8 Gbytes
8 Gbyte

B) 128 Mb per PE (T3Ea)
256 Mb per PE (T3Eb)
(16 PEs on each system have 512 Mb)

2.1.3 Operating system

A) ZOS 1.3

B) UNICOS/mk 2.0.5

2.1.4 External input/output devices

A) 1.2 Terabytes of on-line disk storage

B) 1440 Gbytes (T3Ea)
1920 Gbytes (T3Eb)
39 Terabytes on-line disk storage shared between T3Ea and T3Eb

All systems are LAN attached to desktop PCs, Unix servers and printers

All 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 9940 cartridge drives and a capacity of 5600 cartridge slots.

FileTek StorHouse data server (MASS)

This system is used to archive data, principally data from numeric models. Sun E6500 UltraSPARC processor with 500 Gbyte on-line storage and a StorageTek Powderhorn tape library with a capacity of 5700 cartridge slots giving a total volume storage of 78 Tb, using 16 StorageTek 9840 cartridge drives and 4 StorageTek 9940 cartridge drives (Kelly, 2002).

*An NEC SX-6 supercomputer has been in acceptance trials at Exeter and is expected to replace the T3Es early in 2004.

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 Strike 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 HPUX11. A version of the "Horace" software has been ported onto a Linux operating system operating on a desktop PC and has been deployed under contract to Bermuda, Tanzania 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. 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 met 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.

3. Data and products from GTS in use

3.1 Observations

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

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

3.2 Gridded products

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

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

4. Data input system

Fully automated.

5. Quality control system

5.1 Quality control of data prior to transmission on the GTS

Automatic checks are performed in real time for surface and upper-air data from the UK, Ireland, Netherlands, Greenland and Iceland. Checks are made for missing or late bulletins or observations and incorrect telecommunications format. Obvious errors in an abbreviated heading line are corrected before transmission onto the GTS.

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

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

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

Failure at step 1 is fatal, and the report will not be used. The results of all the remaining checks are combined using Bayesian probability methods (Lorenc and Hammon, 1988).

Observations are assumed to have either normal (Gaussian) errors, or gross errors. The probability of gross error is updated at each step of the quality control, and where the final probability exceeds 50 per cent the observation is flagged and excluded from use in the data assimilation.

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

6. Monitoring of the observing system

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

- Automatic checking of missing and late bulletins.
- Annual monitoring checks of the transmission and reception of global data under WMO data-monitoring arrangements.
- Monitoring of the quality of marine surface data as lead centre designated by CBS. This includes the provision of monthly and near-real-time reports to national focal points, and 6-monthly reports to WMO (available on request from the Met Office, 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 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 (3DVAR)
2) Global atmospheric forecast model
3) Mesoscale atmospheric data assimilation system (3DVAR)
4) Mesoscale atmospheric forecast model
5) Stratospheric global atmospheric data assimilation system (3DVAR)
6) Stratospheric global atmospheric forecast model
7) Transport and dispersion model
8) Nowcasting model
9) Global wave hindcast and assimilation/forecast system
10) Regional wave hindcast and forecast system

11) Mesoscale wave hindcast and forecast system
12) Mesoscale models for sea surge
13) Global ocean model
14) Regional Ocean model
15) Mesoscale Shelf -seas model
16) Nested Shelf-seas model
17) Global single-column (site-specific) model
18) Mesoscale single-column (site-specific) model.

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

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

The latest update run provides initial starting conditions for the forecast runs of the global atmospheric model. The global atmospheric model provides surface boundary conditions for the global and regional wave and ocean models. It also provides lateral boundary conditions for the mesoscale model. The mesoscale forecast model is run four times a day and provides surface boundary conditions for the sea-surge model, 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+120 0150	0230 & - 0405
W00	Regional wave	- 12-00	T+36 0150	0345 G18, G00
W00	Global wave	1200-2400 12-00	T+120 0300	0420 G18, G00
C00	Preliminary single column		T+36 0150	0300 G00
C00	Global single column		T+120 0300	0600 G00
M00	Mesoscale atmosphere	2230-0130 -	T+36 0200	0240 G00
W00	Mesoscale wave	- 18-00	T+36 0200	0300 M18, M00
E00	Mesoscale sea surge		T+36 0200	0250 M18, M00
C00	Mesoscale single column		T+36 0200	0400 M00
S00	Stratospheric atmosphere	2100-0300 -	T+6 0520	- -
O00	Global ocean	24 hours -	T+144 0500	0530 G00
O00	Regional ocean	24 hours -	T+120 0500	0540 G00, O00
Q00	Mesoscale shelf-	-	T+36	0620 M00

	seas	24 hours	0545	
Q00	Nested shelf-seas	- 24 hours	T+36 0545	0630 M00
M03	Mesoscale atmosphere	0130-0430 -	T+4 0655	- G00
U00	Global atmosphere	2100-0300 -	T+9 0700	- -
G06	Global atmosphere	0300-0900 -	T+36 0750	0840 -
C06	Preliminary single column		T+36 0750	0900 G06
Run	**Model**	**Data Hindcast assimilation**	**Forecast cut-off**	**Product boundary available values**
M06	Mesoscale atmosphere	0430-0730 -	T+36 0800	0840 G06
W06	Mesoscale wave	- 00-06	T+36 0800	0900 M00, M06
E06	Mesoscale sea surge		T+36 0800	0850 M00, M06
C06	Mesoscale single column		T+36 0800	1000 M06
S06	Stratospheric atmosphere	0300-0900 -	T+6 1220	- -
U06	Global atmosphere	0300-0900 -	T+9 1255	- -
SST	Sea-surface temperature analysis	0000-2359	- 1310	- -
M09	Mesoscale atmosphere	0730-1000 -	T+4 1315	- G06
G12	Global atmosphere	0900-1500 -	T+120 1350	1430 & - 1605
W12	Regional wave	- 00-12	T+36 1350	1545 G06, G12
W12	Global wave	0000-1200 00-12	T+120 1500	1620 G06, G12
C12	Preliminary single column		T+36 1350	1500 G12
C12	Global single column		T+120 1500	1800 G12
M12	Mesoscale atmosphere	1030-1330 -	T+36 1400	1440 G12
W12	Mesoscale wave	- 06-12	T+36 1400	1500 M06, M12
E12	Mesoscale sea surge	- 06-12	T+36 1400	1450 M06, M12
C12	Mesoscale single column		T+36 1400	1600 M12
U12	Global atmosphere	0900-1500 -	T+9 1905	- -
M15	Mesoscale atmosphere	1330-1630 -	T+4 1930	- G12
G18	Global atmosphere	1500-2100 -	T+36 1955	2045 -
C18	Preliminary single column		T+36 1955	2105 G18
M18	Mesoscale	1630-1930	T+36	2045 G18

	atmosphere	-	2005	
W18	Mesoscale wave	- 12-18	T+36 2005	2105 M12, M18
E18	Mesoscale sea surge	- 12-18	T+36 2005	2055 M12, M18
C18	Mesoscale single column		T+36 2005	2200 M18
S12	Stratospheric atmosphere	0900-1500 -	T+48 2120	2200 -
S18	Stratospheric atmosphere	1500-2100 -	T+6 0020	- -
M21	Mesoscale atmosphere	1930-2230 -	T+4 0030	- G18
U18	Global atmosphere	1500-2100 -	T+9 0100	- -

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

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

7.2.1 Data assimilation, objective analysis and initialisation

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

7.2.2 Forecast model

Basic equations: Non-hydrostatic finite difference model with height as the vertical co-ordinate. Full equations used with (virtually) no approximations. Suitable for running at very high resolution.
Independent variables: Latitude, longitude, eta (η), time.
Primary variables: Horizontal and vertical wind components, potential temperature, pressure, density, specific humidity, specific cloud water (liquid and frozen).
Integration domain: Global.
Horizontal grid: Spherical latitude-longitude with poles at 90°N and 90°S. Resolution: 0.56° latitude and 0.833° longitude. Arakawa 'C'-grid staggering of variables.
Vertical grid: 38 levels
Charney-Philips grid staggering of variables. The normalised vertical co-ordinate η is hybrid in

height, varying from $\eta = 0$ at the surface to the top level at $\eta = 1$, where zero vertical velocity w is applied. The lowest level is purely terrain following and there is a smooth (quadratic) transition to a specified number of 'flat' upper levels where the height of each point at a level is constant.

Integration scheme — Two time-level semi-Lagrangian advection with a pressure correction semi-implicit time stepping method using a Helmoltz solver to include non-hydrostatic terms. Model time-step= 1200 s.

Filtering — Spatial filtering of winds and potential temperature in vicinity of poles.

Horizontal diffusion — Fourth order diffusion along η surfaces of winds, specific humidity and potential temperature.

Vertical diffusion — Second-order diffusion of winds only between 500 and 150 hPa in the tropics (equatorward of 30°).

Divergence damping — Nil.

Orography — GLOBE orography dataset.
1 km data, averaged to 10 km. Before it is used in the model, the data are filtered using a sixth-order low-pass implicit tangent filter, constrained so that the filtering is isotropic in real space.

Surface classification — Sea: global SST analysis performed daily; Sea ice: analysis using NCEP SSM/I.

Physics parametrizations:

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

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

radiation scheme is used (once every nine model time steps).

- Improved numerical formulae for the soil hydrology and thermodynamics.

b) Boundary layer Non-local in unstable regimes.

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

This allows more physical direct coupling between the turbulence forcing of unstable boundary layers and the transports generated within them (rather than the 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 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. Ensembles are also run for monthly and seasonal forecasts (see Sections 7.5 and 7.6). Output from the EPS is post-processed to provide forecasters and customers with numerous chart displays including spaghetti diagrams, ensemble means, individual ensemble members and tracks of both tropical and 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. Chart production was upgraded during the year to take advantage of the second daily run of the EPS made operational by ECMWF, initialised from 0000 UTC analyses.

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 have been added to the database this year 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 and the calibration system lead to significant improvements in probabilities compared to direct ensemble output. Quarterly monitoring of the verification introduced last year is starting to show trends in ensemble performance, with early indications of slight improvements. The EPS is also scanned daily for probabilities of severe weather (severe gales, heavy rain or snow) and issues automatic alerts to forecasters when defined probability thresholds are exceeded. This system incorporates considerable calibration to assess probabilities explicitly in the form required to support the UK National Severe Weather Warning Service. Verification shows that 4-day forecasts of severe weather have useful probabilistic skill, but 2-day forecasts are much less useful. Most of the skill comes in the form of low-probability warnings.

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

7.3.1 Data assimilation

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

Analysis variables	As 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 64ºN-44ºN, 12ºW-13ºE).

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

Physics parametrizations:

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

7.3.3 Operational techniques for application of NWP products

Output is increasingly automatically generated from the NWP output, with little or no human intervention. 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).

7.4 Specialized forecasts

7.4.1 Nowcasting system

Nimrod produces analyses and forecasts of precipitation and many other weather parameters (including precipitation type, visibility, snow probability, cloud amount (3-D), cloud- base and cloud-top height, lightening probability, wind speed and direction, maximum gust intensity and towering convection) for the period T+0 to T+6 hours. Forecasts are normally produced by merging an extrapolation forecast with an NWP model forecast. These products are generated hourly at a resolution of either 15 or 5 km. However, rainfall forecasts are also produced with a 5 km resolution every half hour and with 2 km resolution every 15 minutes. A variety of soil moisture products are also produced at 5 km resolution. The Nimrod cloud and precipitation analyses are used as inputs to the mesoscale model assimilation scheme.

There are now two versions of Nimrod running, the original one (UK Nimrod) and European Nimrod.

Grid	UK national grid for UK Nimrod and a similar Tranvserse Mercator Projection for European Nimrod: 2- and 5-km resolution for precipitation products; 5 or 15km resolution the other products. The UK Nimrod domain is an approximation to the mesoscale model domain (roughly 44^o N-64^o N, 12^o W-13^o E). The European Nimrod domain extends from 30^oW to 43^oE at 60^oN and from 10^oW to 25^oE at 35^oN.
Data inputs	Radar imagery from the UK and European radars, Meteosat visible and infrared imagery, mesoscale model forecast fields (UK Nimrod), global model forecast fields (European Nimrod) and surface weather reports.
Forecast time step	5 minutes for precipitation forecasts; 60 minutes for other forecasts.
Special features	Radar rain rates automatically corrected for the effects of bright-band, range and orographic growth, using a physically-based method (Kitchen *et al.,* 1994).

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

Model type	Developed from Bryan-Cox ‘level’ model on Arakawa B-grid. Includes a Kraus-Turner mixed-layer scheme, and a thermodynamic/simple advection sea-ice model.
Integration domain	Global.
Horizontal grid	1^o x 1^o.
Vertical grid	20 levels; 10 of the levels are in the top 300 m, the deepest is at 5192 m.
Data assimilation	Based on the Timely Optimal Interpolation scheme of Bell *et al.* (2003), including a 2-component inhomogeneous 3-D error covariance model. Temperature and salinity profile data, sea-surface temperature data (in-situ and AVHRR), gridded SSM/I sea-ice concentration data are assimilated, using a nudging technique.
Surface fluxes	From the global NWP model, 6-hourly.

7.4.3 Wave hindcast and forecasting system: global wave model

Model type	Coupled-discrete (SWAMP, 1985)
Integration domain	Global
Grid	Spherical latitude-longitude from 80.2778ºN 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).

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

Model type	Developed from Bryan-Cox ‘level’ model on Arakawa B-grid. Includes a Kraus-Turner mixed-layer scheme and a thermo-dynamic/simple-advection sea-ice model.
Integration domain	Atlantic/Arctic.
Horizontal grid	1/3º x 1/3º. Rotated grid with pole at 17ºN 56ºE
Vertical grid	20 levels; 10 of the levels are in the top 300 m, the deepest is at 5192 m.
Data assimilation	Based on the Timely Optimal Interpolation scheme of Bell et al (2003), 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	From the global FOAM

7.4.5 Wave hindcast and forecasting system: regional wave model

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

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

7.4.6 Wave hindcast and forecasting system: local wave model

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

Model type	Coupled discrete; depth dependency specified to 200 m with 2-m resolution
Integration domain	North-West European continental shelf
Grid	Spherical latitude-longitude from 48°N to 63°N and 12°W to 13°E. Resolution: 1/9° latitude, 1/6° longitude
Boundary forcing	1) 10-m winds from the mesoscale NWP model, updated hourly (for 48-hour forecast, four times daily). Winds from the global NWP model for 120-hour forecast, twice daily) 2) Spectral values at lateral boundaries from the global wave model, updated hourly
Surface classification	No sea ice. Surface currents from the operational storm-surge model, updated hourly (not used in the 5-day forecast)
Physics parametrizations	Identical to the global model, without great-circle turning of swell, plus calculation

of the effect of time-varying currents on wave-energy spectrum.

7.4.7 Shelf-seas forecast model

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

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

7.4.8 Nested coastal ocean model

Model type	Baroclinic piecewise parabolic advection scheme, Mellor Yamada turbulent mixing. Hybrid co-ordinate.
Integration domain	Irish Sea.
Grid	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 3) River inflows – daily climatology, data provided from Environment Agency.
Surface classification	No sea ice; no wetting or drying.

7.4.9 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 1/9° by 1/6° resolution covering 48°N to 63°N, 12°W to 13°E, and is forced at the deep-ocean boundaries by 15 tidal harmonic constituents. The model is run 4 times daily, using hourly values of surface pressure and 10-m winds from the mesoscale NWP model to provide a 36-hour forecast.

7.4.9 Tropical cyclone forecasts

Initialisation of tropical cyclones is achieved by the creation of bogus data which are fed into the numerical forecast model. Tropical cyclone advisory bulletins received on the GTS from various tropical cyclone warning centres are used to provide the input data to this process. The creation of tropical cyclone bogus data is totally automated, but forecasters in the 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 WWW site.

7.4.10 Stratospheric model

A stratospheric configuration of the operational global data assimilation and forecast system has been run at the Met Office for a number of years. It is based on the system described in section 7.2, but with additional stratospheric levels, and lower horizontal resolution. In October 2003, a new version of the stratospheric model was introduced, using the New Dynamics scheme. At the same time, a spectral gravity-wave drag parametrization scheme (Scaife *et al.,* 2002; Warner and McIntyre, 1999) was implemented, along with a simple methane oxidation scheme. The data assimilation scheme uses a 3-D variational technique (implemented in November 2000).

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 degrees latitude by 3.75 degrees longitude. Variables staggered on an Arakawa C-grid
Data Assimilation	3-D variational data assimilation scheme (Lorenc *et al.* 2000).

7.4.11 Transport and dispersion model (NAME)

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

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

7.4.12 Trajectory Model

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

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

7.5 Extended range forecasts

A key activity this year has been the development of extended-range products using a monthly-range ensemble forecast system developed by ECMWF.

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 fortnightly from initial conditions at 00GMT Wednesday.

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

Products include global probability forecasts and more detailed forecasts for the 10 UK climate districts. Global probability products are provided to forecasters in the form of probability maps for tercile categories of temperature and precipitation. For the 10 UK climate districts temperature and rainfall forecasts are generated in terms of equiprobable quintile categories; well below, below, near normal, above, well above, while 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: For each forecast the population of quintile and tercile categories is determined relative to a model climatology defined by a set of hindcasts, each with the same start time and valid periods as the forecast. The hindcasts are performed for the 12-year period 1990 to 2001 in a 5-member ensemble.

7.6 Long-range forecasts

A new 40-ensemble coupled ocean-atmosphere global seasonal prediction system (known as GloSea) was implemented as the Met Office’s real-time system in March 2003, with forecast production moved towards operational status. GloSea, a version of the HadCM3 climate model, has replaced the “two-tier” 9-ensemble HadAM3 system (forced with persisted SST anomalies), formerly used for real-time seasonal prediction since January 1998. 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.

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 Data Assimilation (ODA): The ODA scheme is based on the Met Office FOAM system (Bell *et al.,* 2000), which uses a form of optimal interpolation.

- 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, 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.
- 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.

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 are made available to NMSs (via a password protected website), Regional Climate Outlook Fora, UK government agencies, the public (www.metoffice.com/research/seasonal/) and to 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. Both probability and deterministic forecast maps are produced for the globe and a number of regional areas. For probability forecast maps a two category format is used, i.e. the probability that the anomaly will be above or below zero (based on the ensemble distribution). For deterministic forecast maps the anomaly sign and magnitude is provided (based on the ensemble mean). Information on the long-term skill of the forecast is also made available. In addition to the map products site-specific products, based on rolling monthly-mean anomalies, are also generated for various sites in Europe.

Model calibration: 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 against	T+24	T+72	T+120
RMS error (m)	Z 500	Northern Hemisphere	Analyses	10.85	30.05	55.15
RMS error (m)	Z 500	Southern Hemisphere	Analyses	14.78	38.82	67.53
Statistic	**Paramete**	**Area**	**Verified**	**T+24**	**T+72**	**T+120**

	r		against			
RMS error (m)	Z 500	North America	Observations	11.57	29.90	54.45
RMS error (m)	Z 500	Europe	Observations	12.23	30.59	57.08
RMS error (m)	Z 500	Asia	Observations	13.08	25.30	43.21
RMS error (m)	Z 500	Australia/New Zealand	Observations	11.95	22.77	39.18
RMS vector wind error (ms^{-1})	W 250	Northern Hemisphere	Analyses	4.19	9.37	14.66
RMS vector wind error (ms^{-1})	W 250	Southern Hemisphere	Analyses	4.63	10.40	16.09
RMS vector wind error (ms^{-1})	W 250	North America	Observations	6.41	11.68	17.37
RMS vector wind error (ms^{-1})	W 250	Europe	Observations	5.81	11.30	17.34
RMS vector wind error (ms^{-1})	W 250	Asia	Observations	6.19	10.29	14.28
RMS vector wind error (ms^{-1})	W 250	Australia/ New Zealand	Observations	6.17	10.07	14.30
RMS vector wind error (ms^{-1})	W 850	Tropics	Analyses	2.09	3.30	3.98
RMS vector wind error (ms^{-1})	W 250	Tropics	Analyses	3.51	6.41	8.07
RMS vector wind error (ms^{-1})	W 850	Tropics	Observations	4.20	5.05	5.51
RMS vector wind error (ms^{-1})	W 250	Tropics	Observations	5.96	7.57	8.83

9. Plans for the future

9.1 Computer systems

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

The NEC SX-6 delivered in 2002 (Baylis *et al.,* 2002) will replace the current Cray T3Es in 2004.

All 30 SX-6 nodes and peripherals that make up the NEC supercomputer have been installed in the IT halls at Exeter. The system is underwent trials during the second half of 2003 and is due to be accepted during January 2004.

An enhancement to the SX-6 is due to be delivered in the first quarter of 2005; it will effectively double our supercomputing power.

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

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

The Met Office, having successfully located to its new HQ in Exeter, is now 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 about two 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.

9.2 Data assimilation

The assimilation capability of the European area model will be developed further to allow better use of conventional observations. Upgrades to the mesoscale data assimilation system during 2004 may include:

- Variational assimilation of cloud fraction data to replace current nudging approach
- Quality Control of visibility observations
- A new daily soil moisture analysis taken from an independent Soil State Diagnosis Model run as part of the Nimrod nowcasting system.

Work will continue to concentrate developing our 4D-VAR capability for the global model for operational implementation in 2004. Initially, the current 3D-VAR system will be ported and optimised for operational implementation on the new supercomputing platform, the NEC SX-6.

Other plans for 2004 include:

- Improved use of ATOVS, including an upgraded radiative transfer model RTTOV-7 and introduction of data for high altitude land areas;
- Introduction of AIRS and AMSU-A temperature and moisture retrievals from the Aqua satellite;
- Introduction of MODIS polar winds.

9.3 Atmospheric forecast models

Short-range forecasting system

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

Monthly and seasonal forecast system

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

Stratospheric model

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

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

9.4 Ocean, wave and surge forecast models

Wave models

Wave-energy spectra from the ENVISAT level 2 advanced synthetic aperture radar observations are routinely retrieved with global coverage, for comparison with the global wave model.

Ocean forecast models

A 1/9º model of the North Atlantic, nested into the 1/3º Atlantic FOAM, and a 1/9º model of the Mediterranean are being run pre-operationally. The 1/9º North Atlantic model may be transitioned to operational running during 2004.

Shelf Seas forecast models

In collaboration with the Proudman Oceanographic Labroatory and Plymouth Marine Laboratory, a hindcast and eventual nowcast for the coupled physical-ecosystem of the NW European Shelf Seas is being prepared using the POLCOMS-ERSEM model, at ~6 km resolution.

9.5 Nowcasting system

Meteosat Second Generation products will be introduced into Nimrod and the satellite processing moved off Nimrod at the same time. The quality control of radar data will also be moved off Nimrod. All the forecasts currently on the UK version of Nimrod will me introduced onto the European version. An improved precipitation-type forecast will be introduced, giving the probability of each precipitation type. A post-processing system for a high resolution NWP model for the UK will be designed and a start made on implementation. This will eventually replace the UK version of Nimrod.

9.6 Transport and dispersion model

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

9.7 Tropical cyclone forecasting

Once the global model has moved onto the new NEC SX-6 supercomputer, trials of a higher resolution model will be undertaken. In conjunction with this, the tropical cyclone initialisation scheme will be optimised to realise the full benefits of a higher resolution model.

9.8 Seasonal forecasting and climate modelling

In 2004 the range of seasonal forecast products will be extended to include tercile category forecasts of temperature and precipitation, and predictions of SST evolution in the standard tropical Pacific “Nino” regions.

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