**Progress Report on the Global Data Processing System, 1999**
**United Kingdom**
**The Met. Office (Bracknell)**

## 1. Summary of highlights

### 1.1 Forecast models

The main changes to the global versions of the Unified Model in the suite for numerical weather prediction were the following:

| | |
|---|---|
| 28 January 1998 | The resolution of the global model was increased to 0.55º x 0.833º (60km at mid latitudes), and 30 vertical levels. |
| 15 April 1998 | The Limited Area Model (LAM) was replaced by early runs of the global model at the same resolution. |
| 12 May 1998 | A new global orography was introduced, with significant corrections over Antarctica. |

The main changes to the mesoscale version of the Unified Model in the suite for numerical weather prediction were the following:

| | |
|---|---|
| 10 June 1998 | The domain of the mesoscale model was increased so that it covers the region 44ºN-64ºN, 12ºW-13ºE. The horizontal resolution was increased to 12km, and the number of vertical levels increased to 38. |
| 27 January 1999 | All four UK mesoscale runs were extended to T+36 for products and T+48 for backup. |
| 5 May 1999 | A new boundary layer scheme and soil moisture scheme (MOSES) were introduced. |
| 12 October 1999 | A new radiation scheme was introduced - the Edwards-Slingo scheme. |

The main changes to the wave and ocean models in the suite were the following:

| | |
|---|---|
| 25 May 1999 | A high-resolution (60km) global wave model was introduced, including shallow water physics. |
| 13 July 1999 | We started to assimilate sea-ice concentration data into our FOAM ocean model. |
| 21 July 1999 | Global assimilation of wave observations, including ERS-2 altimeter data, was introduced. |

The main changes to the Nimrod nowcasting system were as follows:

| | |
|---|---|
| 10th June 1998 | The Nimrod domain was extended in line with changes to the mesoscale model. |
| 1st June 1999 | A 2km-resolution forecast of thunderstorm precipitation was introduced. |

### 1.2 Observations, quality control and assimilation

Routine monitoring provides regular revisions to acceptance lists for Synops, Aircraft and Sondes. In addition the following major changes to the system were made:

| | |
|---|---|
| February 24 1999 | Meteosat-5 satellite winds (over the Indian Ocean) were introduced. |
| March 10 1999 | We started to use high level (above 400hPa) GMS satellite water-vapour winds. |
| March 29 1999 | We introduced a global 3DVAR system as replacement for the analysis correction scheme. Assimilation of 1D-Var retrievals from NOAA-15 ATOVS were thinned to one report per 2 degree |
| May 5 1999 | We introduced hourly assimilation of radar data into the UK area mesoscale model (previously 3 hourly) |

| | |
|---|---|
| July 6 1999 | Sea-ice analysis using SSM/I data was introduced. |
| July 20 1999 | The global data assimilation system was upgraded: We revised the covariance model use of ATOVS over Siberia, and thinned scatterometer winds to one per analysis grid box |
| October 12 1999 | We introduced 3DVAR for UK area mesoscale model as a replacement for the analysis correction scheme |
| October 19 1999 | The global data assimilation system was upgraded:<br>• We started to use SSM/I windspeeds thinned to one report per 125 km<br>• We introduced the direct assimilation of (A)TOVS radiances in 3DVAR<br>• We made more use of station pressure rather than pmsl<br>• We updated the statistics for the covariance model<br>• Aircraft obs errors were reduced and modest thinning was introduced. |

## 2. Equipment in use at the centre

### 2.1 Centralised systems

A) Front end mainframe computers

B) Supercomputers

2.1.1 Make and model of computer

A) IBM 9672 – R45
IBM 9672 – R25

B) Cray T3Ea (880 PEs)
Cray T3Eb (640 PEs)
(PE – Processor Element)

2.1.2 Main Storage

A) 2 Gbytes (R45)
1 Gbyte (R25)

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

2.1.3 Operating system

A) OS/390 Version 2 Release 5

B) UNICOS/mk 2.0.4

2.1.4 External input/output devices

A) 720 Gbytes DASD
1 Gbyte semi-conductor disk
LAN attached Desktop PCs,
Workstations and printers
2 line printers
2 microfiche processors

B) 1440 Gbytes (T3Ea)
1440 Gbytes (T3Eb)

48 magnetic cartridge drives connected
to a GRAU automated tape library system
with a capacity of 28,800 cartridges.
Connectivity to both the 9672 and the T3E.

### 2.2 Desktop systems for forecasters

The workstation-based ‘Horace’ system is used for visualisation and production and is operational in the National Meteorological Centre (NMC), Bracknell, and at other major operational locations in the UK.
Each user site comprises at least one Hewlett Packard UNIX data server plus as many multi-screen workstations, printers and plotters as are necessary to meet the local requirements. Communications services via a message switch provide every type of observational data from the GTS, while an ftp server provides the imagery, rainfall and numerical weather prediction (NWP) files.

## 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 typical of late October, excluding data received but not yet processed for assimilation.

| Observation Group | Observation Sub-group | Items used | Daily Extracted | % used in assimilation |
|---|---|---|---|---|
| Ground-based vertical profiles | TEMP | T, V, RH processed to model layer average | 1100 | 97 |
| | PILOT | As TEMP but V only | 800 | 99 |
| | PROFILER | As TEMP but V only | 200 | 0 |
| Satellite-based vertical profiles | TOVS | Radiances directly assimilated with channel selection dependent on surface, instrument and cloudiness | 21000 | 20 |
| | ATOVS | | 360000 | 4 |
| Aircraft | Manual AIREPS | T, V as reported with duplicate checking and blacklist | 13000 | 80 |
| | Automated ACARS/AMDAR/ ASDAR | | 51000 | 40 |
| Satellite atmospheric motion vectors | GOES 8,10 | High res. 'BUFR' IR winds | 50000 | 25 |
| | Meteosat 5,7 | IR, VIS and WV winds | 10000 | 98 |
| | GMS 5 | IR, VIS and WV winds | 5000 | 92 |
| Satellite-based surface | ERS-2 | In-house wind vector retrieved from backscatter | 170000 | 10 |

| | | | | |
|---|---|---|---|---|
| | SSMI-13 | In-house 1DVAR wind speed retrieval (not moisture yet) | 500000 | 2 |
| Ground-based surface | Land Synop | Pressure only (processed to model surface) | 25000 | 80 |
| | Ship Synop | Pressure and Wind | 5500 | 90,96 |
| | Buoy | Pressure | 5000 | 60 |

**3.2 Gridded Products**

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

Products received from Météo France, DWD 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**

Both manual and 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 q.c. 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 on 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 Meteorological Office, Bracknell).
- Monthly monitoring of the quality of other data types and the provision of reports to other lead centres or national focal points. This monitoring feeds back into the data assimilation by way of revisions to reject list or bias correction.

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

- Generating data coverage maps from each model run (available on the Web).
- A real-time monitoring capability that provides timeseries of observation counts, reject counts and mean/r.m.s. departures of observation from model background. Departures from the norm are highlighted to trigger more detailed analysis and action as required.

## 7. Forecasting system

The forecasting system consists of:

1. Global atmospheric data assimilation system
2. Global atmospheric forecast model
3. Mesoscale atmospheric data assimilation system
4. Mesoscale atmospheric forecast model
5. Transport and dispersion model
6. Nowcasting model
7. Global wave hindcast and assimilation/forecast system
8. Regional wave hindcast and forecast system
9. Regional model for sea-surge.
10. Global ocean model.

The global atmospheric model runs with 3 different data cut-off times:

- 2 hours (preliminary run);
- 3 hours (main run); and
- 7 hours (update run).

The latest update run provides initial starting conditions for both the early preliminary and main runs of the global atmospheric model. The global atmospheric model provides surface boundary conditions for the global wave and ocean models. The preliminary global provides lateral boundary conditions for the mesoscale model, and surface boundary conditions for the regional wave model. The mesoscale forecast model is run four times a day and provides surface boundary conditions for the sea-surge model. The global wave model system includes the assimilation of wave height and wind speed observations from the altimeter on ERS-2. The global wave model provides lateral boundary conditions for the regional wave model. The nuclear accident model is run when needed.

**7.1 System run schedule**

| Run | Model | Data assimilation | Hind-cast | Fore-cast | Cut-off | Product available | Boundary values |
|---|---|---|---|---|---|---|---|
| P00 | Preliminary Global Atmosphere | 2100-0300 | - | T+36 | 0155 | 0230 | - |
| W00 | Regional wave | - | 12-00 | T+36 | 0155 | 0240 | P18, P00 |
| M00 | Mesoscale Atmosphere | 2230-0130 | | T+36 | 0200 | 0240 | P00 |
| G00 | Global Atmosphere | 2100-0300 | - | T+120 | 0305 | 0405 | - |
| W00 | Global wave | 1200-0000 | 12-00 | T+120 | 0305 | 0420 | G18,G00 |
| O00 | Global Ocean | 24 hours | - | T+144 | 0520 | 0545 | G00 |
| M03 | Mesoscale Atmosphere | 0130-0430 | - | T+3 | 0545 | - | P00 |
| U00 | Global Atmosphere | 2100-0300 | - | T+6 | 0715 | - | - |
| P06 | Preliminary Global Atmosphere | 0300-0900 | - | T+36 | 0755 | 0830 | - |
| M06 | Mesoscale Atmosphere | 0430-0730 | - | T+36 | 0800 | 0840 | P06 |
| M09 | Mesoscale Atmosphere | 0730-1030 | | T+3 | 1205 | - | P06 |
| U06 | Global Atmosphere | 0300-0900 | - | T+6 | 1305 | - | - |
| SST | SST Analysis | 0000-2359 | - | - | 1310 | - | - |
| P12 | Preliminary Global Atmosphere | 0900-1500 | - | T+36 | 1355 | 0230 | - |
| W12 | Regional wave | - | 00-12 | T+36 | 1355 | 1440 | P06,P12 |
| M12 | Mesoscale Atmosphere | 1030-1330 | - | T+36 | 1400 | 1440 | P12 |
| G12 | Global Atmosphere | 0900-1500 | - | T+120 | 1505 | 1605 | - |
| W12 | Global wave | 0000-1200 | 00-12 | T+120 | 1505 | 1620 | G06,G12 |
| M15 | Mesoscale Atmosphere | 1330-1630 | - | T+3 | 1905 | - | P12 |
| U12 | Global Atmosphere | 0900-1500 | - | T+6 | 1920 | - | - |
| P18 | Preliminary Global Atmosphere | 1500-2100 | - | T+36 | 2000 | 2035 | - |
| M18 | Mesoscale Atmosphere | 1630-1930 | - | T+36 | 2005 | 2040 | P18 |
| M21 | Mesoscale Atmosphere | 1930-2230 | - | T+3 | 0005 | - | P18 |
| U18 | Global Atmosphere | 1500-2100 | - | T+6 | 0105 | - | - |

NB: The global Atmosphere and wave model run out to T+144 for backup purposes only. The preliminary global atmosphere and regional wave models run out to T+48 for backup purposes only.

**7.2 Medium range forecasting system (4-10 days): Global model**

*7.2.1 Data assimilation*

| | |
|---|---|
| Analysed variables | Velocity potential, stream function, unbalanced pressure and relative humidity. |
| Analysis domain | Global. |
| Horizontal grid | Half model resolution (see 7.2.2) but using an Arakawa C grid. |
| Vertical grid | Same levels as model (see 7.2.2) but using a Charney-Phillips staggering. |
| 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 introduced gradually into the model using an Incremental Analysis Update (Bloom et al, 1996) over 6-hour period (T-3 to T+3). |

*7.2.2 Forecast model*

| | |
|---|---|
| Basic equations | Hydrostatic primitive equations with approximations accurate on planetary scales (White & Bromley, 1995). Fourth order accurate advection. |
| Independent variables | Latitude, longitude, eta, time. |
| Dependent variables | Horizontal wind components, potential temperature, specific humidity, specific cloud water (liquid and frozen), surface pressure, soil temperature, soil moisture content, canopy water content, snow depth, sea-ice temperature, boundary-layer depth, sea-surface roughness. |
| Diagnostic variables | Geopotential, vertical velocity, convective-cloud base, top, amount, and layer-cloud amounts. |
| Integration domain | Global. |
| Horizontal grid | Spherical latitude-longitude with poles at 90ºN and 90ºS. Resolution: 0.56º latitude, and 0.83º longitude. Variables staggered on Arakawa B-grid. |
| Vertical grid | 30 levels, hybrid co-ordinates (  = A/po +B);<br>layer boundaries at 1.0, 0.994, 0.956, 0.905, 0.835, 0.75, 0.70,0.65, 0.60,0.55, 0.50,0.45,0.41, 0.37,0.34, 0.31, 0.29,0.26,0.21,0.19, 0.165, 0.140,0.115,0.090, 0.065, 0.040, 0.020, 0.010, 0.0005;<br>levels are (assuming surface pressure of 1000 hPa): 997, 975, 930, 880, 827,775,725, 675,625,575, 525, 475,430, 390,355,327, 302, 277,252,227, 202, 177,152,127,102, 77, 52, 30, 15, 4.6 hPa. |
| Integration scheme | Split-explicit finite difference. Adjustment uses forward-backward scheme, second-order accurate in space and time. Advection uses a two-step Heun scheme with fourth-order accuracy. Adjustment timestep =133.3s; advection timestep =400s; physics timestep =1200s. |
| Filtering | Fourier damping of mass-weighted winds and mass-weighted increments to potential temperature and humidity. Adapts to strength of wind at each latitude. |
| Horizontal diffusion | Linear fourth order with coefficient K = 2.0 x $10^7$ (but linear, second order on top level with K = 7.0 x $10^5$) for winds, liquid potential temperature and total water content. No diffusion where co-ordinate surfaces are too steep (near orography). |
| Vertical diffusion | Second-order diffusion of winds only between 500 & 150 hPa in Tropics (equatorwards of 30º). |
| Divergence damping | Nil. |
| Orography | Grid-box mean, standard deviation and sub-grid-scale gradients (for gravity wave surface stress) derived from US Navy 10' dataset. Orographic roughness parameters linearly derived from standard deviation, and from 1 km data (N.America) and 100m data (Europe). |
| Surface classification | Sea: global SST analysis performed daily.<br>Sea ice: Analysis using ice edge data from Washington Joint Ice Center. No partial cover, thickness = 2m.<br>Land: geographical specification of vegetation and soil types that determine surface roughness, albedo, heat capacity, and surface hydrology; snow amount from modified monthly climatology of Willmott et al. (1985). |

Physics parametrizations:

| | |
|---|---|
| a) Surface and soil | Multi-layer soil-temperature model. Soil-moisture and surface-moisture flux prediction scheme with surface canopy store (Warrilow and Buckley, 1989). Sea-surface roughness dependent on wind speed (Charnock |

| | |
|---|---|
| | constant = 0.12). Surface fluxes of heat, moisture and momentum dependent on surface roughness and local stability. |
| b) Boundary layer | Turbulent fluxes in lowest 5 layers depend on moist local stability and low-cloud cover (Smith, 1990). Implicit integration scheme. Non-local mixing of heat and moisture in unstable conditions. Form drag effects modelled via an effective roughness length calculated from the silhouette area of unresolved orography and standard deviation of orography height within the grid box. |
| c) Cloud/precipitation | Liquid and ice content included. Large-scale precipitation takes into account accretion and coalescence for rain. Frozen cloud starts precipitating as soon as it forms (Smith, 1990). Evaporation of precipitation depends on phase, temperature and rate. |
| d) Radiation | Fully interactive using 6 bands in the long-wave and 4 in solar calculations. Long-wave gaseous transmission adapted from Morcrette *et al.* (1986). Fractional cloud in all moist layers and convective tower. Cloud emissivity and optical properties depend on phase and water content (Slingo, 1989). |
| e) Convection | Penetrative mass-flux scheme based on a simple cloud model (Gregory and Rowntree, 1990). Initial mass flux depends on buoyancy. Downdraught representation included. Convective momentum transports included. CAPE closure dependence, with adjustment timescale of 1 hour. |
| f) Gravity-wave drag | Surface stress estimated from sub-grid variance of orography and the orography gradient vector; high drag states, flow blocking, and drag due to trapped lee waves are represented. Vertical stress profile for hydrostatic waves is determined by critical saturation stress law similar to Palmer et al., (1986). |

*7.2.3 Numerical weather prediction products*

RSMC Bracknell issues products on the GTS from the global numerical forecast models using several data formats. The character-based format is GRID (FM47-IX Ext.) and the binary format is GRIB (FM92-X Ext.). Production of obsolete GRIB Edition 0 ceased during the year. NWP model fields are interpolated onto regular latitude-longitude grids arranged in adjacent areas to give global coverage in GTS bulletins that do not exceed the GTS size limit. The regular products from the global atmospheric and wave models are on a 2.5º x 2.5º degree resolution. WAFS bulletins from the atmospheric model in the Thinned GRIB format of 140 km (1.25º x 1.25º degrees at the equator) are available over SADIS, but these bulletins, and the rest of the bulletins making up a full forecast product, are also available over high capacity links on the GTS. Graphical products can also be produced as T.4 faxes and Computer Graphic Metafiles (CGMs). Fields from the atmospheric model include geopotential height, temperature, horizontal wind on all standard levels, vertical velocity and relative humidity on some standard levels, mean sea level pressure and precipitation. From the wave model, height, direction and period of total significant wave, swell and wind-sea are available. Forecast times include the analysed data (T+0) and at 6 or 12 hour steps out to T+120. More detailed information is available in the "List of Numerical Weather Prediction Products Available from Bracknell", published by the Meteorological Office.

In the event of a system failure at Bracknell, backup procedures are started when it becomes apparent that delays to the current run will lead to failure to meet the output schedules. At present this occurs if there is a delay of 20 minutes to the global model output. If the delay is less than 12 hours, all the normal output is generated from the previous run. The previous T+36 becomes the new T+24, for example, and the previous T+12 becomes the new T+0. If the delay is greater than 12 hours, and the previous run was not completed, then a limited number of products based on output from Washington WMC are issued in place of the normal Bracknell output.

*7.2.4 Operational techniques for application of NWP products*

A set of Model Output Statistics Products is generated from NWP global model forecast data from the 00Z and 12Z runs out to 6 days ahead. Day-maximum and night-minimum temperature forecasts for 750 stations world-wide and Probability of Precipitation over 6 and 12 hour periods for 300 European stations are produced. The NWP forecast data are sent to a system called FSSSI (Forecasting for Specific Sites: System Implementation) which contains a relational database, and are then run through a set of Kalman Filters to produce the forecasts. Later, the verifying observations are extracted to the database where the Kalman Filters are updated for the new observations. The forecasts are sent to other product generating systems where the data is formatted as an end product.

*7.2.5 Ensemble prediction system*

Ensemble predictions systems are run for routine monthly and seasonal forecasts (see Sections 7.5 and 7.6). For medium range forecasting, the ECMWF Ensemble Prediction System (EPS) is utilised.

Output from the EPS is post-processed to provide forecasters with numerous chart displays of ensemble mean, individual ensemble members and clusters of members. Probability forecast information for 41 specific sites around the British Isles are also generated, along with a comprehensive verification system for their assessment.

## 7.3 Short-range forecasting system (0-72 hrs): Mesoscale model

*7.3.1 Data assimilation*

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

| | |
|---|---|
| Analysis variables | As global (see 7.2.1) but also includes aerosol content. |
| Analysis domain | As model integration domain (see 7.3.2). |
| Horizontal grid | Half model resolution (see 7.3.2), but using an Arakawa C grid. |
| Vertical grid | As model levels, but using a Charney-Phillips staggering. |
| 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) but with divergence damping of $7.2 \times 10^4\ m^2 s^{-1}$ included. |
| Assimilation cycle | Continuous sequence of 3-hourly mesoscale assimilation cycles. |
| Initialisation | 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). The precipitation analysis is also used to calculate assimilation increments to the canopy water, soil moisture and snow depth fields. 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 forecast model is identical to the global model in all respects except the following:

| | |
|---|---|
| Integration domain | British Isles and 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. |

| | |
|---|---|
| Vertical grid | 38 levels, hybrid co-ordinates ( = A/p0 +B);<br>layer boundaries at 1.000, 0.9976, 0.9929, 0.9835, 0.9719, 0.958, 0.940, 0.921, 0.901, 0.880, 0.858, 0.835, 0.810, 0.780, 0.745, 0.705, 0.660, 0.610, 0.555, 0.500, 0.450, 0.410,0.370, 0.340,0.310, 0.290, 0.265, 0.240,0.215,0.190, 0.165, 0.140, 0.115, 0.090,0.065, 0.040, 0.020, 0.010, 0.0005;<br>levels are (assuming surface pressure of 1000 hPa): 999, 995, 988, 978, 965, 949, 930, 911, 890, 870, 846, 822, 795, 762, 725, 682, 635, 582, 527, 475, 430, 390, 355, 327, 302, 277, 252, 227, 202, 177, 152, 102, 77, 52, 30, 15, 4.6 hPa. |
| Timestep | Adjustment timestep = 25s; advection timestep = 75s; physics timestep = 300s. |
| Horizontal diffusion | Linear fourth-order with coefficient 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 | Grid-box mean and variance derived from 5' NCAR dataset. Orographic roughness parameters derived from 100m data. |
| Boundary values | Specified from preliminary global forecast model with same data time (forecasts from 00, 06, 12 and 18 UTC) |
| Physics parametrizations: | |
| a) Surface | Met. Office surface exchange scheme (MOSES I), Cox et al, 1999, which includes:<br>• a Penman-Monteith surface flux formulation, with a 'skin' surface temperature;<br>• a 4-layer coupled soil hydrology and thermodynamics model; and<br>• an interactive canopy resistance model.<br>Land use characteristics are based on 10-minute data, rather than 1 degree |
| b) Boundary layer | A new turbulent mixing scheme (Lock et al, 1999; Martin et al, 1999). 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 flexible two-stream code (1996). Calculated on chequerboard pattern for every other grid box and heating rates interpolated from same land-sea types. Updated hourly with solar angle updated each timestep. |
| e) Convection | Updated version of Gregory and Rowntree scheme (1990) to include downdraught parametrization and revised evaporation formulae dependent on the precipitation rate. |
| f) Gravity-wave drag | None. |

*7.3.3 Numerical weather prediction products*

As described in section 7.2.3, except for the following:

- NWP model fields are interpolated onto regular latitude-longitude grids arranged in adjacent areas covering Europe and the North Atlantic. The regional products from the atmospheric model are currently on either a 1.25º x 1.25º or a 2.5º x 2.5º degree resolution. The regional wave model products are on a 1.25º x 1.25º degree resolution.
- Forecast times include the analysed data (T+0) and at 3 or 6 hour steps out to T+36.

- Backup procedures are started when there is a delay of 10 minutes to the regional output. If the delay is less than 6 hours, all the normal output is generated from the previous run. The previous T+36 becomes the new T+30, for example, and the previous T+12 becomes the new T+6. If the delay is greater than 12 hours, and the previous run was not completed, then products from the run 12 hours before are used.

*7.3.4 Operational techniques for application of NWP products*

- A set of Model Output Statistics Products is generated from NWP preliminary global model forecast data from the 00Z and 12Z runs out to 2 days ahead. Day-maximum and night-minimum temperature forecasts for 500 European stations and Probability of Precipitation over 6 and 12 hour periods for 300 European stations are produced. The NWP forecast data are sent to FSSSI (see section 7.2.4)
- A set of one-dimensional Site Specific Forecast Model (SSFM) forecasts with high resolution in the boundary layer and sub-surface are run using mesoscale model and preliminary global model data as forcing data. 790 UK and near continent sites are run 4 times per day from the mesoscale model out to T+36 and 112 world-wide sites 4 times per day from the preliminary global model also out to T+36. The data are sent to FSSSI. Initialising data for the SSFM are extracted from previous runs and sent with the forcing supercomputer to run the SSFM. The forecast output is returned to FSSSI where it is packaged and further processed into a number of products for onward dissemination. Some of the further processing includes Road Surface Temperature modelling, Automatic TAF generation software and further Model Output Statistics processing.

## 7.4 Specialised forecasts

*Nowcasting system*

Nimrod produces analyses and forecasts of precipitation and supplementary weather parameters (including precipitation type, visibility, snow probability and lightning rate), at 5 km resolution, for the period T+0 to T+6 hours. Forecasts are produced using a combination of linear extrapolation and model wind advection, with precipitation forecasts from the mesoscale model used to introduce an element of growth/decay. In addition, analyses and forecasts of cloud amount (3-D), cloud base and cloud top height are generated. These products are generated hourly at a resolution of 15 km. The Nimrod cloud and precipitation analyses are used as inputs to the mesoscale model assimilation scheme.

| | |
|---|---|
| Grid | UK national grid: 2 and 5 km resolution for precipitation products; 15 km resolution for cloud products. The domain is an approximation to the mesoscale model domain (roughly 44ºN-64ºN, 12ºW-13ºE). |
| Data inputs | Radar imagery (from the network of 15 sites within the UK, Ireland and Jersey), Meteosat visible and infrared imagery, mesoscale model forecast fields and surface weather reports. |
| Forecast timestep | 10 and 15 minutes for precipitation forecasts; 60 minutes for cloud and visibility forecasts. |
| Special features | Radar rain rates automatically corrected for the effects of bright-band, range and orographic growth using a physically based method (Kitchen et al., 1994) |

*Ozone and UV forecasts*

In 1993, ozone column forecasts were established at the Met. Office using empirical relationships between ozone and meteorological parameters. From the ozone forecast, clear sky UV amounts were predicted (Austin et al., 1994). In spring 1999, the Meteorological Office UV forecasts were extended to take into account the impact of cloud. This was achieved by applying empirical relationships to the clear sky UV assuming the forecast cloud amounts. Cloud corrected forecasts are now broadcast and supplied to the media.

*Tropical cyclone forecasts*

Initialisation of TC's is achieved by the creation of bogus data, which are fed into the numerical forecast model. TC advisory bulletins received on the GTS from various TC warning centres are used to provide the input data to this process. The creation of TC bogus data is totally automated, but forecasters in the National Meteorological Centre (NMC) at the Met. Office have the facility to over-ride the automatic system and create their own bogus data if required. Full details of the bogus technique may be found in Heming *et al.* (Met. Apps, 2, 1995).

*Transport and dispersion model*
A model for medium and long-range transport and dispersion (NAME, version 3.0) is available to be run in the event of a major atmospheric release of hazardous pollutants, such as in a nuclear emergency or volcanic eruption.  It can also be used for routine pollution problems, such as acid rain and air quality. It provides forecasts of concentrations in the boundary layer and at upper levels, as well as wet and dry deposition to the surface. It uses analysis and forecast fields from the global and mesoscale atmospheric models maintained in on-line archives. The NAME model may be run at any time in hindcast or forecast mode.

| | |
|---|---|
| Model type | Three-dimensional Lagrangian multiple-particle Monte Carlo model simulating the medium or long-range transport, dispersion and deposition of airborne pollutants, including accidentally released radionuclides. |
| Integration domain | Global or UK mesoscale, nested as required. |
| Model grid | Identical to the global and UK mesoscale models, but with some vertical levels omitted. The transport model can access fields from both input models simultaneously, with an option to use the best resolution available at every particle position. The output grid can be customer-defined, and of any resolution. |
| Dynamical input | Meteorological fields from the global or UK mesoscale models. |
| Integration scheme | Forward timestep, determined by the diffusion scheme near to the source, but with an option for definition by the user in the longer ranges. |
| Parametrization | Comprehensive near-source random walk diffusion scheme with option of uniform or non-homogeneous vertical profiles of the turbulent velocity variances and, for the convective boundary layer, an option for non-Gaussian statistics. Simpler, homogeneous scheme at longer ranges, or an option for basic K-diffusion. There are also schemes for low-frequency wind meandering, plume rise, gravitational settling, the venting of pollutants from the boundary layer by strong convection, and a novel technique allowing for small-scale entrainments at the boundary layer top. Radioactive decay; wet and dry deposition, with provision for conversions from gas to particulate; turbulent (occult) deposition over hills. New gaseous and aqueous phase sulphur and nitrogen chemistry. |
| Special features | 10-day high-resolution (6 km) archive of rainfall rate, derived from radar products, used for wet deposition over NW Europe; effects of orographic enhancement and scavenging by snow include. Automated adjustments to plume spread and source emission profile from observed radiology using least-squares techniques. Source attribution scheme. |

*Global ocean model - FOAM (Forecast Ocean Atmosphere Model)*

| | |
|---|---|
| Model type | Developed from Bryan-Cox 'level' model on Arakawa B-grid. Includes a Kraus-Turner mixed layer scheme, and a thermodynamic/simple advection sea ice model. |
| Integration domain | Global. |

| | |
|---|---|
| Horizontal grid | 1º x 1º. |
| Vertical grid | 20 levels. 10 of the levels are in the top 300m, the deepest is at 5192m. |
| Data assimilation | Based on the UKMO analysis correction scheme. Assimilates temperature profile data, and sea surface temperature data (in-situ and AVHRR). Gridded SSMI sea-ice concentration data are assimilated, using a nudging technique. |
| Surface fluxes | From global NWP model, 6-hourly. |

*Wave hindcast and forecasting system: Global wave model*

| | |
|---|---|
| Model type | Coupled discrete (SWAMP, 1985); deep-water solution only. |
| Integration domain | Global. |
| Grid | Spherical latitude-longitude from 80.3ºN to 79.2ºS. Resolution: 5/9º latitude, 5/9º longitude. |
| Frequency resolution | 13 frequency components spaced logarithmically between 0.04Hz and 0.324Hz. |
| Direction resolution | 16 equally spaced direction components. |
| Data assimilation | ERS-2 altimeter wave-height observations are assimilated into the global wave model, using the altimeter wind-speed to separate wind-sea and swell. The assimilation scheme (Thomas, 1988, and Stratton *et al.*, 1990) is a variant of the analysis-correction scheme of Lorenc *et al.* (1991). After assimilation the model wave height matches the analysed wave height, the model wind-sea matches the analysed wind-speed, and the pattern of the spectrum remains similar to that before assimilation. |
| Integration scheme | Modified Lax-Wendroff. Source terms timestep = 1800s; advection timestep frequency dependent. |
| Boundary forcing | Winds at lowest level of global atmospheric model (sigma=0.997). Updated hourly. |
| Surface classification | Sea ice analyses as in the global atmospheric model. |
| Physics parametrizations: | Linear growth (Phillips, 1958); exponential growth (Snyder, 1981); white-capping dissipation (Komen et al., 1984). Non-linear transfer of wave energy is parametrized by enforcing a JONSWAP spectral shape on the wind-sea. A parametrization of directional relaxation in turning winds is included, and a term accounting 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 windsea growth. For all but actively growing windsea, the dissipation coefficient is reduced by one half of the specified value. Shallow water terms are included (shoaling, bottom friction, refraction) |

*Wave hindcast and forecasting system: Regional wave model*

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

| | |
|---|---|
| Model type | Coupled discrete; depth dependency specified to 200m with 2m resolution. |
| Integration domain | European continental shelf and Mediterranean, Baltic and Black Seas. |
| Grid | Spherical latitude-longitude from 67.7ºN to 30.5ºN, and from 14.1ºW to 41.9ºE. Resolution: 0.25º latitude, 0.4º longitude. |
| Source terms timestep | 1800s. |
| Boundary forcing | 1. Winds at lowest level of regional atmospheric model (sigma=0.997). Updated hourly.<br>2. Spectral values at lateral boundaries from global wave model. Updated hourly. |
| Surface classification | No sea ice. |
| Physics parametrizations: | Identical to global model, without great-circle turning of swell. |

*Storm Surge model*

A depth-averaged storm surge model, developed by the Proudman Oceanographic Laboratory, is run operationally on behalf of MAFF (Ministry of Agriculture, Fisheries and Food) for the Storm Tide Forecasting Service. The model is implemented on a grid at 1/9 by 1/6 degree resolution covering 48-63N, 12W-13E, 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 10m winds from the mesoscale NWP model to provide a 36 hour forecast.

**7.5 Extended range forecasts (10 days to 30 days)**

Extended range and experimental seasonal range forecasts are produced from 4-month, 9-member AGCM ensemble integrations forced with persisted Sea Surface Temperature (SST) anomalies. Forecasts are produced weekly on Thursdays.

Model: The HadAM3 climate version of the global model is used (Pope et al. 1999). The resolution is 2.5$^{o}$ latitude, 3.75$^{o}$ longitude and 19 vertical levels. The timestep is 30 minutes. The model is run in a 9-member ensemble.

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

SST and sea-ice forcing: SST anomalies from climate observed for the 4-week period lagging the initialisation date by 10 days are persisted throughout the integration, updating every 5 days. SST forcing is the same for all members. Projected changes in sea-ice cover are also represented.

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

Forecast variables: The main forecast variables are mean, maximum and minimum temperature, accumulated precipitation and sunshine amount, averaged over three forecast periods: days 4-10, days 11-17 and days 18-31. For each ensemble member, global forecast values are derived from direct averaging of daily model output. For the UK region only, values are also derived using regression equations on the forecast period-averaged pmsl field and observed local SST.

Forecast formats: Temperature and rainfall forecasts are mainly presented in terms of equiprobable quintile categories; Well Below, Below, Near Normal, Above, Well Above – defined by the 1961-90 climate. Tercile categories are used for some forecasts. The forecast is expressed both in terms of the probability of each category and as a single deterministic forecast based on the ensemble mean.

**7.6 Long range forecasts (30 days up to 2 years)**

The model ensemble system used for long (seasonal) range forecasts is identical to that used for extended range forecasts (Section 7.5). The seasonal forecast products are experimental and are available to National Met. Services through a password protected internet site.

Forecast variables: Forecasts are provided for anomalies in 3-month-average 850 hPa temperature (as a proxy for surface temperature) and precipitation. Forecasts at zero lead (months 1-3 of the integration) and 1 month lead (months 2-4 of the integration) are produced. The 3-month averages are calculated from daily model values (at 12Z) and expressed as anomalies from the model climatology appropriate to the forecast period.

Forecast format: Both probability and deterministic forecasts are produced. For probability forecasts a two category format is used, i.e. probability that the anomaly will be above or below zero (based on the ensemble distribution). For deterministic forecasts the anomaly sign and magnitude is provided (based on the ensemble mean). Products are provided in map format for the globe and a number of regional areas and with optional skill templates, which mask out regions in which the model currently has no significant skill.

## 8. Verification of prognostic products

| Statistic | Parameter | Area | Verified against | T+24 | T+72 | T+120 |
|---|---|---|---|---|---|---|
| RMS error(m) | Z 500 | N.Hem | Analyses | 13.08 | 34.11 | 61.43 |
| RMS error(m) | Z 500 | S.Hem | Analyses | 19.96 | 50.10 | 78.56 |
| RMS error(m) | Z 500 | N.America | Observations | 15.24 | 35.36 | 63.00 |
| RMS error(m) | Z 500 | Europe | Observations | 15.09 | 33.30 | 64.80 |
| RMS error(m) | Z 500 | Asia | Observations | 17.87 | 28.14 | 43.42 |
| RMS error(m) | Z 500 | Aus/NZ | Observations | 15.76 | 29.55 | 47.40 |
| RMSVW error (m/s) | W 250 | N.Hem | Analyses | 4.85 | 10.43 | 16.12 |
| RMSVW error (m/s) | W 250 | S.Hem | Analyses | 5.73 | 12.57 | 18.23 |
| RMSVW error (m/s) | W 250 | N.America | Observations | 6.86 | 12.32 | 18.72 |
| RMSVW error (m/s) | W 250 | Europe | Observations | 6.65 | 11.49 | 18.18 |
| RMSVW error (m/s) | W 250 | Asia | Observations | 7.09 | 10.82 | 14.36 |
| RMSVW error (m/s) | W 250 | Aus/NZ | Observations | 7.27 | 11.68 | 16.35 |
| RMSVW error (m/s) | W 850 | Tropics | Analyses | 2.30 | 3.53 | 4.23 |
| RMSVW error (m/s) | W 250 | Tropics | Analyses | 4.10 | 6.72 | 8.36 |
| RMSVW error (m/s) | W 850 | Tropics | Observations | 4.10 | 4.94 | 5.46 |
| RMSVW error (m/s) | W 250 | Tropics | Observations | 6.19 | 7.69 | 8.97 |

1. The annual figures shown above are averages of the 12 monthly statistics running from January to December 1999. The statistics are derived according to the standard verification methods specified by the CBS.
2. All results show the average of the 00 UTC and 12 UTC values at T+24, T+72, and T+120.

## 9. Plans for the future

### 9.1 Computer systems

a) Installation of a StorageTek Automated Tape Library with StorageTek 9840 cartridge drives.

b) Installation of a Mass Storage System

### 9.2 Data assimilation.

Two upgrade cycles are anticipated for the global data assimilation system during 2000. Some possible candidates for inclusion are:

- The use of model background time interpolated to observation time;
- A new system for defining radiosonde bias corrections of height and relative humidity;
- Intelligent thinning of ATOVS and revised channel selection;
- Use of observed rather than 'retrieved' ATOVS/TOVS radiances;
- To determine Synoptic Dependent Error Modes (SBEMs) from an error breeding cycle and use them to modify the analysis increment structure through a new control variable;
- To present dual scatterometer winds to 3DVAR for implicit ambiguity removal;
- To introduce a stratospheric extension to the model, with implied improvement to upper level analyses;
- Introduction of geostrophic co-ordinate transform, which gives greater validity to the assumptions of homogeneity and isotropy in the background error covariance in the vicinity of fronts;
- To make more use of Synop reports (temperature, wind, humidity);
- To use new Satwind sources, and a more intelligent thinning;
- A revised ATOVS bias correction strategy (especially for stratosphere);
- The use of Profilers; and
- The use of SSMI Total Water.

Two upgrade cycles are anticipated for the mesoscale data assimilation system during 2000. Some possible candidates for inclusion are:

- A revision of forecast error covariance statistics, especially horizontal length scales and proportion of energy in divergent wind;
- Inclusion of European radar data to UK weather radar composite, and improved treatment of errors in radar data; and
- Improved consistency of analysis with boundary data from global model, by interpolation of global analysis increments to the mesoscale domain to make a first guess for the mesoscale analysis.

### 9.3 Atmospheric forecast models

The global forecast physical parametrizations will be updated to be in line with the mesoscale model. The Edwards-Slingo radiation, cloud ice microphysics and surface scheme (MOSES I) will be implemented. It is also planned to increase the number of levels to 38, and to use the new turbulent boundary layer scheme.

The global orography will be based on the GLOBE dataset of 30-second arc resolution.

Changes to the cloud parametrizations to include a representation of convective anvils and cloud area will also be tested in both global and mesoscale versions.

A new dynamical formulation will be assessed and prepared for operational implementation in late 2001.

ECMWF ensemble output will be post-processed specifically to attempt to predict the probability of severe weather conditions, to provide forecasters with a first-guess of early warnings.

A version of the operational forecast model has been vertically extended with an upper boundary of 10Pa (approx. 65 km). The model is being tested to determine whether there is a positive impact on weather forecasting. The benefits may accrue from two sources, an improved initialisation and an improved simulation due to the extra levels themselves. Currently work is in progress in setting up a data assimilation scheme to address the first issue, with an extensive set of trials due to start when this is available.

**9.4 Nowcasting System**

The resolution of some of the rainfall products will be increased to 2km. The cloud analysis system will be developed to incorporate data from the MSG satellite when available.

**9.5 Tropical cyclone forecasting**

We plan to use more of the available incoming advisory data in the TC initialisation procedures. Further enhancements to the TC initialisation procedure are being tested for possible implementation in 2000.

**9.6 Transport and dispersion model**

- Improved free tropospheric turbulence parametrizations;
- Addition of near-source capabilities;
- Use of ensemble forecast products; and
- Adaptation as urban air quality model.

**9.7 Ocean, wave and surge forecast models**

*Ocean Forecast models*.

A 1/3-degree model of the Atlantic and Arctic is being developed, with a southern boundary at 30S nested into global FOAM. Models at 1/9 degree nested into the 1/3 degree Atlantic model are also under development. Methods to assimilate altimeter sea surface height data are being developed and applied.

*Wave models*

A new grid for UK waters has been set up at 1/9 by 1/6 degree resolution covering 48-63N, 12W-13E, the same as the operational storm surge model. Wave model formulation has been extended to include a comprehensive treatment of wave-current effects, taking surface currents from the operational storm surge model. This wave model is being assessed. The new models have not yet been implemented for operational use.

Wave energy spectra from the ERS-2 SAR observations are routinely retrieved for selected areas, using the iterative retrieval scheme developed by Hasselman et al, at the Max Planck Institute for Meteorology, Hamburg.

*Shelf Seas forecast models*

The CCMS-POL Shelf Seas Model (Proctor and James 1996) on the NW European shelf area (1/9 by 1/6 degree resolution covering 48-63N, 12W-13E) has been adapted to run using surface forcing from numerical weather prediction models. Starting from climatology on 1 March 1998 the model has been run with surface heating (6-hourly averages) and hourly winds and pressures from the global weather prediction model. The model now runs in near real time and is being prepared for operational implementation, which is scheduled during March 2000.

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