



Numerical Weather Prediction

Development of the North Atlantic European model (NAE) into an operational model



Forecasting Research Technical Report No. 470

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11th May 2006

Abstract

A project was set up in NWP in November 2001 to look at the feasibility of removing the duplication of Preliminary Global (QP) and Main Global runs (QG). The release of computer time could then be used to run a regional model over the North Atlantic and Europe. This would have a number of potential customers and would enable this main region of interest to be modelled at higher resolution than is possible with the Global model. Further benefits were foreseen including improved (higher resolution) lateral boundary conditions for the UK Mesoscale model and a possible rationalisation of the Crisis Area Mesoscale models (CAMM's).

This Technical report looks at the development of the North Atlantic European Model (NAE) from its initiation (when it was known as the European model) and introduction into the Operational Suite in December 2002 through to the final 20km version of the model in January 2005. The model was upgraded with full data assimilation in August 2003 and a further upgrade to the data assimilation in September 2004 allowed the model to gain full Operational status. At the same time the model was renamed from the European model to the North Atlantic European model or NAE.

Historical summary

- 17/05/02: Project Initiation
- 05/12/02: Cycle E1: Introduction of the European model into the Operational Suite.
- 02/06/03: Withdrawal from the Operational Suite for Transition.
- 12/08/03: Cycle E2: European model reinstated with full data assimilation.
- 03/12/03: Cycle E3: Upgrade to UM5.5 (previously UM5.3)
- 16/12/03: Introduction of revised orography.
- 07/01/04: Change to the Critical Froude number and surface gravity wave constant.
- 23/03/04: Replacement of the Balkans Model (last run 30/03/04).
- 27/04/04: Upgrade to UM6.0 and port of the SCS suite to the NEC.
- 22/09/04: Cycle E4: DA/UM upgrade allows the NAE to gain Operational status.
- 18/01/05: Cycle E5: Final 20km version of the model with revised domain.

1) Project Initiation

A project was set up in NWP in November 2001 to look at the feasibility of removing the duplication of Preliminary Global (QP) and Main Global runs (QG). The release of computer time could then be used to run a regional model over the North Atlantic and Europe. This would have a number of potential customers and would enable this main region of interest to be modelled at higher resolution than is possible with the Global model. Further benefits were foreseen including improved (higher resolution) lateral boundary conditions for the UK Mesoscale model and a possible rationalisation of the Crisis Area Mesoscale models (CAMM's).

A paper outlining the feasibility was discussed at a meeting in December 2001 involving representatives from across the Met Office including the Numerical Modelling and Forecasting Research sections of NWP, the Operations Centre (Chief Forecaster), Aviation, Business and International. Implications for the Operational Core Suite, Product Suite and HORACE were discussed with representatives in Spring 2002 and the 1st Project Board Meeting was held on the 17th May 2002.

The main implication of removing Global QP runs was that Global QG runs would have their data cut-off reduced from 3 hours 05 minutes to 1 hour 50 minutes. Summer and Winter Trials were carried out to assess the impact and a Parallel Trial was run during Autumn 2002. These tests were deemed to be successful and the change was implemented operationally on 03/12/02 as cycle G29.

2) Introduction of the European model into the Operational Suite (05/12/2002)

2.1 Model set-up

Initially there were just two runs of the model per day (QY06 and the QY18) running out to T+36. These forecasts were run from reconfigured Global analyses. Charts on Metnet enabled forecasters to view the output.

2.2 Ancillary files

Ancillary files were generated and the following climatologies and potential Climatologies configured during the reconfiguration from Global:

- 1) Ozone (qrclim.ozone)
- 2) Soil Moisture (qrclim.smow)
- 3) Deep soil temperature (qrclim.slt)
- 4) Volumetric soil moisture concentration at wilting point (qrparm.soil)
- 5) Volumetric soil moisture concentration at critical point (qrparm.soil)
- 6) Volumetric soil moisture concentration at saturation (qrparm.soil)
- 7) Saturated hydraulic conductivity (qrparm.soil)
- 8) Clapp-Hornberg B parameter (qrparm.soil)
- 9) Thermal capacity of soil (qrparm.soil)
- 10) Thermal conductivity of soil (qrparm.soil)
- 11) Saturated soil water suction (qrparm.soil)
- 12) Snow-free soil albedo (qrparm.soil)
- 13) Soil carbon content (qrparm.soil)
- 14) Fractional covering of surface types (qrparm.veg.frac)
- 15) Leaf area index of plant functional types (qrparm.veg.func)
- 16) Canopy height of plant functional types (qrparm.veg.func)
- 17) Grid-box-mean canopy conductance (qrparm.veg.func)
- 18) Total aerosol concentration (qrclim.murk)
- 19) Source and sink terms (qrclim.murk)

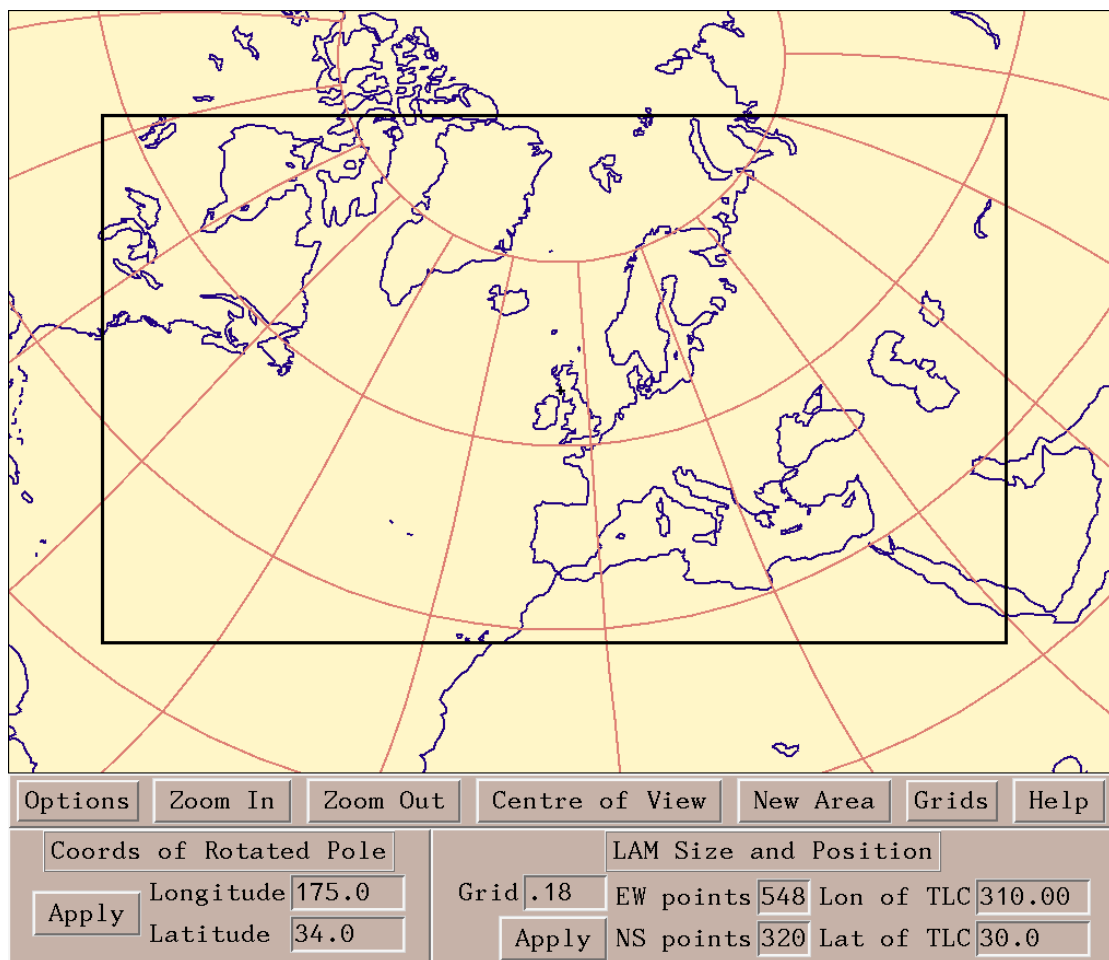
Other ancillary files configured were:

- 20) Orography (qrparm.rog)
- 21) Standard deviation of orography (qrparm.rog)
- 22) Orographic roughness (qrparm.rog)
- 23) Land-Sea-Mask (qrparm.mask)

2.3 Model domain, grid, resolution and timestepping

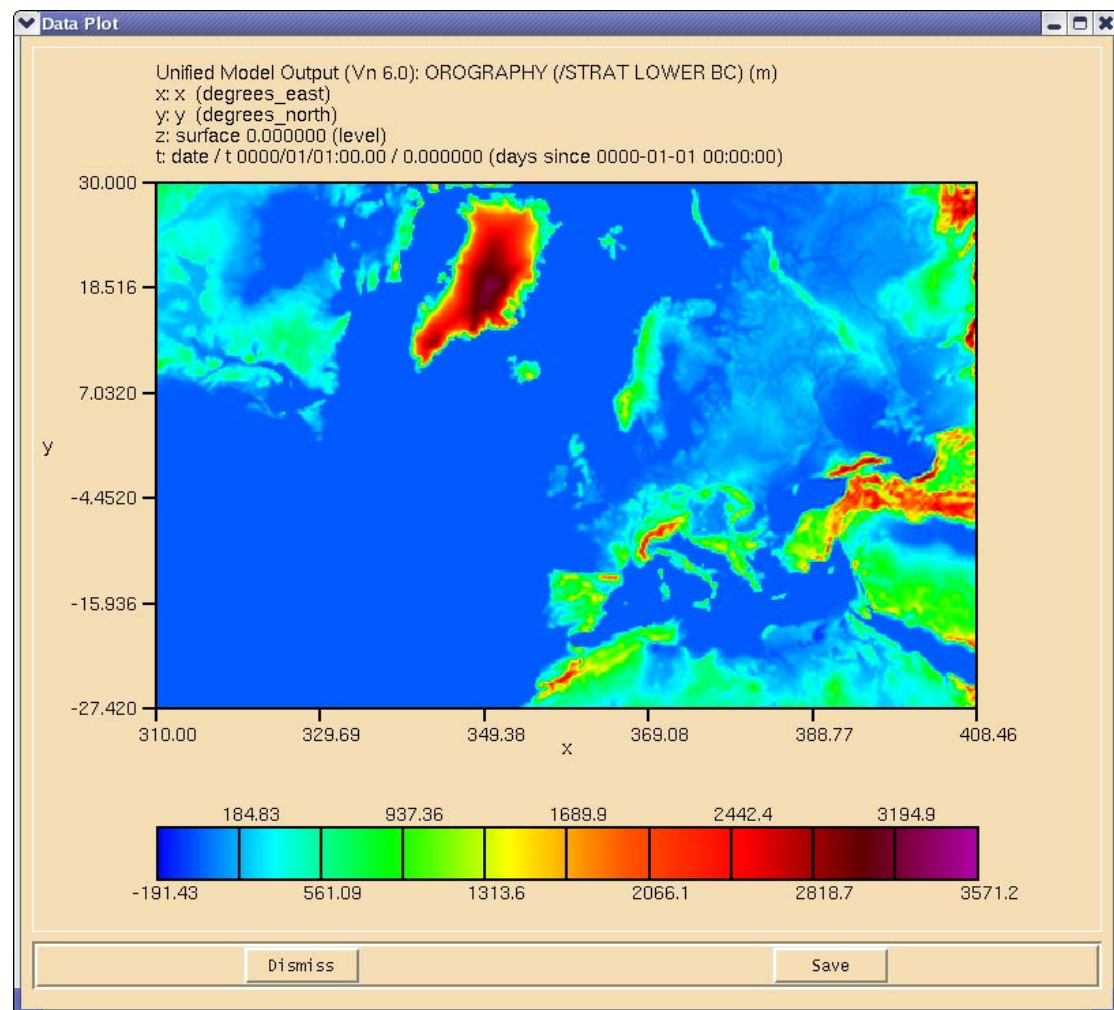
Number of gridpoints East-West: 548
Number of gridpoints North-South: 320
Model grid spacing: 0.18 degrees (~ 20km)
Rotated Pole Longitude: 175.0
Rotated Pole Latitude 34.0
Model Timestep: 7 ½ minutes

Figure 1: Model domain



The rationale behind the choice of model domain (Figure 1) was that if forecasts for Europe were to be improved, then the whole of the North Atlantic needed to be included so that the development of low pressure systems could be modelled at high resolution. Part of North America was included so that SYNOP and TEMP data could be assimilated to give as good an analysis as possible in this important region. The whole of Greenland was included as it was thought that having a boundary crossing the high plateau of Greenland (Figure 2) would produce undesirable noise in the forecast. Similar considerations for the Southern boundary meant that the whole of the Atlas mountains were included. The final choice of domain involved refinements to account for USAF(E) requirements.

Figure 2: Model Orography



2.4 Other Model details

2.4.0 Overview

The model is grid-point based and uses a rotated latitude-longitude grid that ensures a quasi-uniform grid length over the whole integration domain.

It uses a height-based grid in the vertical, which is terrain-following near the surface but evolving to constant height (above sea-level) at model top. There are 38 levels in the vertical with 13 boundary layer levels and 4 deep soil levels.

Charney Phillips grid staggering is used in the vertical whereby vertical velocity and potential temperature are held at the half levels. The Arakawa C grid staggering is used in the horizontal.

Boundary conditions for the model are provided by Global forecast fields interpolated onto the NAE model co-ordinates. A merging zone of up to 8 points is allowed for with weights of 5*1.0, 0.75, 0.5, and 0.25. The effective boundary is therefore located 5 points into the LAM region. This arrangement allows for Courant numbers significantly greater than one.

2.4.1 Dynamics

The NAE (like other versions of the UM) uses the non-hydrostatic form of the governing equations, making the model suitable for use at very high resolutions. The equation set also includes the extra terms normally ignored when making the shallow atmosphere assumption, thus allowing a complete representation of the Coriolis force. (White and Bromley, 1995).

A semi-implicit scheme is used to solve the governing equations. It is designed to conserve mass, mass-weighted potential temperature and moisture, and angular momentum.

The equations are integrated using a predictor-corrector method, which requires the solution of a 3-dimensional, Helmholtz-type equation using a generalised conjugate residual technique. Initial estimates of the prognostic variables are obtained by semi-Lagrangian advection using a two-level scheme (Bates *et al*, 1993). For potential temperature a non-interpolating scheme is used in the vertical.

No horizontal or vertical diffusion was applied at this stage although the targeted diffusion of moisture was subsequently included when the model was upgraded to UM5.5 (see section 5).

2.4.2 Physics

The following parametrization schemes are used in the NAE model configuration:

Cloud: Smith (1990) prognostic cloud scheme based on conserved variables T_L and q_T and a sub-grid scale probability distribution of these variables, from which the cloud amounts and water contents are derived using an assumed critical relative humidity. The scheme is modified such that only water clouds are defined from T_L and q_T and a sub-grid probability distribution. Ice water content is determined by the mixed phase microphysics scheme with ice cloud fraction calculated diagnostically from ice water content. An additional parametrization to derive cloud area as well as volume is included.

Radiation: Modified version of Edwards and Slingo (1996) scheme based on rigorous solution of the two-stream scattering equations including partial cloud cover. Full treatment of scattering and aerosols. Consistent treatment of cloud radiative properties in solar and thermal regions of spectrum. Ice crystals are treated as non-spherical. Some simplifications are made for speed of computation (compared to Global). The radiation scheme is called every hour.

Boundary Layer: Scheme with stability dependent surface exchanges based on Monin-Obukhov length. Boundary layer mixing scheme diagnoses 7 boundary layer types with non-local mixing and explicit entrainment parametrization for unstable boundary layers, local Richardson number-based scheme used for stable layers. (Lock *et al*, 2000). Additional shear driven turbulent BL (type 7) is included.

Precipitation: Bulk microphysics scheme with one ice variable and explicit calculation of transfers between vapour, liquid and ice phases. Cloud microphysics

with an additional ice variable and explicit calculation of transfers between vapour, liquid and ice phases. (Wilson and Ballard, 1999).

Convection: Modified mass flux scheme including changes to diagnosis and triggering of deep and shallow convection. CAPE closure is based on humidity threshold. Convective momentum transport is included as is the representation radiative effects of anvils. The convection scheme is called twice per timestep

Land Surface interaction: Met. Office Surface Exchange Scheme (MOSES) II: Additionally includes "tile" scheme with separate surface-atmosphere fluxes calculated for each surface type present in a given gridbox. (Essery et al, 2002) The number of tiles was set to 1 as the use of 9 tiles (as specified in the U.K Mesoscale model) was deemed to be too expensive.

Soil moisture is reset to climatology every Wednesday (like the Global model).

Gravity Wave Drag: Flow blocking scheme that simplifies diagnosis of hydrostatic gravity waves and low level drag based on Froude Number. Plus GLOBE orography. (Webster et al, 2002)

2.5) Performance

Figure 3: Global model precipitation accumulation with a maximum over Southern France of 111mm in 36 hours.

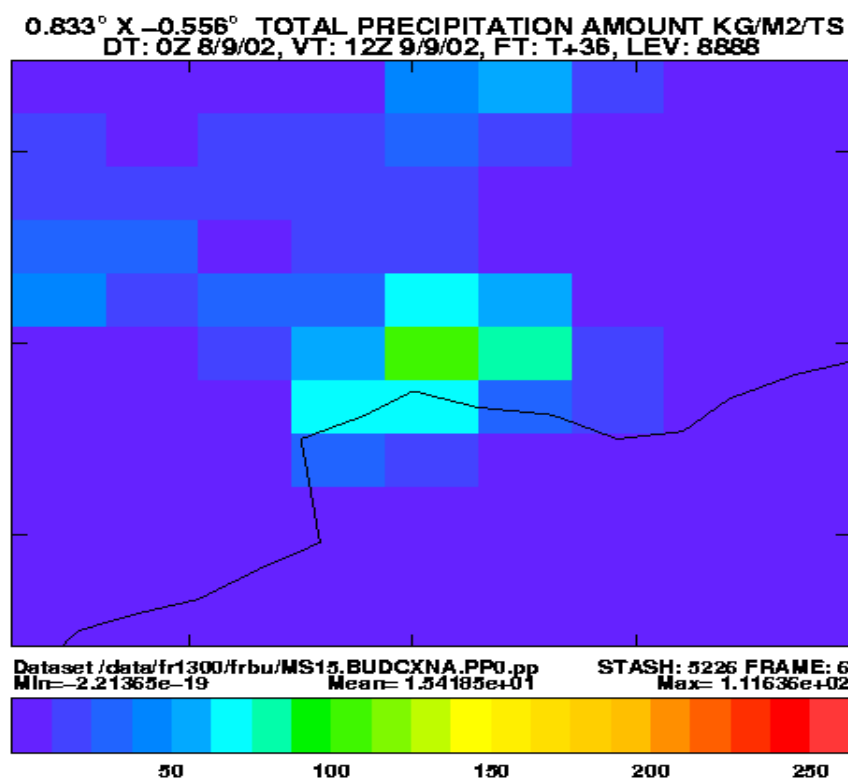
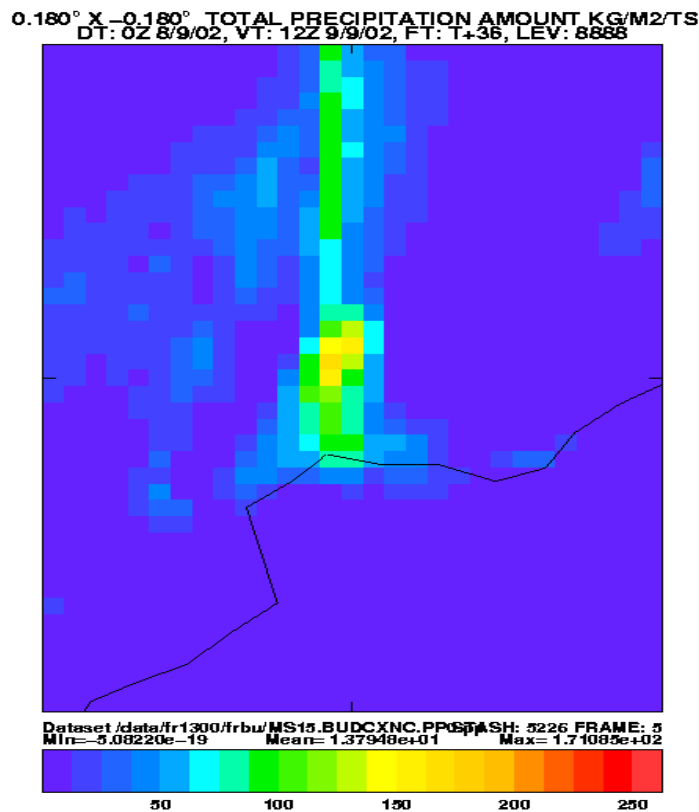


Figure 4: NAE model precipitation accumulation with a maximum over Southern France of 171mm in 36 hours.



The higher horizontal resolution of the NAE compared to the Global model allows the NAE to produce more intense precipitation features as demonstrated by simulations of the intense precipitation over Gard (Southern France) during the 8th and 9th of September 2002. Observations showed accumulations in excess of 600mm in 48 hours. Neither the Global model nor the NAE managed to get values as extreme as this, but the NAE produced 171mm in 36 hours compared to 111mm in the Global.

2.6 Operational Failures

A failure on 06/01/2003 was caused by the way the reconfiguration treated sea ice. Small values of sea ice fraction (less than 0.5) were found to be the cause and so a new reconfiguration executable was introduced on 04/02/2003 setting any values less than 0.5 to zero. This made the reconfiguration consistent with the Sea ice analysis performed in other UM configurations.

A number of failures in March 2003 were caused by an inconsistency between the ancillary fields for soil moisture content and volumetric soil moisture content at saturation. The problem was solved by generating a new soil moisture content field.

3) NAE withdrawal from the Operational Suite for Transition (02/06/2003)

The move of the Met Office HQ from Bracknell to Exeter placed an extra strain on computing resources and while the T3EB was unavailable due to its move to Exeter, the NAE was withdrawn from the Operational Suite from 02/06/2003 to 12/08/2003.

4) Introduction of Data Assimilation (12/08/2003)

4.0 Overview

The Met Office 3-D variational scheme (Lorenc et al, 1999) is similar in design to those in use elsewhere, but has been developed so that it can be used for both global and limited area grid-point models. A development path from a 3-D to a 4-D scheme is included in the design

The 3D-Var scheme uses a horizontal analysis grid equivalent to half the resolution of that used by the forecast. The raw analyses are unsuitable for starting a forecast. To overcome this lack of initialisation, the Incremental Analysis Update scheme (Bloom et al., 1996) is used to introduce analysis increments $1/N^{\text{th}}$ at a time over N timesteps centred on the nominal analysis time.

4.1 Implementation in the NAE

One major difference from the Global system is the presence of boundaries. A constraint of zero analysis increments is specified at the lateral boundaries. This approach is made possible because up-to-date boundary conditions are used and we can therefore assume that there will be no difference between the Global and NAE analyses along this interface. This allows a double sine transform to be used for the horizontal filtering of the control variables

The NAE 3D-Var scheme follows the basic design of the Global system. However the Data Assimilation settings were based upon those implemented in the Extended Middle East Model on 18th February 2003. This consisted of 6 hourly cycles with two forecasts to T+9 (QY00 and QY12) and two forecasts to T+36 (QY06 and QY18). The data assimilation increments were put in via the IAU scheme but there were no AC increments as MOPS was not included.

Unlike the Data Assimilation in the Extended Middle East Model, there is a daily update of sea ice and assimilation of visibility observations.

4.2 OPS/VAR/SURF builds

- OPS build: 12.7
- VAR build: 19.4
- SURF build: 14.4

4.3 Covariance statistics and horizontal lengthscales

The Middle East Model used U.K Mes covariance statistics as there had not been time to generate its own statistics. However for the NAE, covariance statistics were generated using T+12 and T+24 forecast differences from 08/03/03-10/03/03 (23cases).

The following horizontal lengthscales and ExtraNormF values were specified:

hScaleAp=100*130.,
hScaleChi=100*180.,
hScaleLogm=90.,
hScaleMu=100*90.,
hScalePsi=100*130.,
ExtraNormFPsi=0.09,
ExtraNormFChi=0.11,
ExtraNormFAp=0.27,

The ExtraNormF values are smaller than those in the Middle East or U.K Mes models. The reason for choosing smaller values was that the Operational Middle East model had suffered from a number of grid point storms during the Spring/Summer of 2003. It was suspected that large analysis increments (e.g. theta increments of up to 10K at model level 1) might have been the cause of these grid point storms.

Smaller ExtraNormF values lead to smaller analysis increments as less weight is given to the observations. The values were chosen by doing a single ob experiment in which a pseudo temperature observation with an o-b of 1 degree was put into the U.K Mes and NAE models. The ExtraNormF values in the NAE were then adjusted until they gave the same magnitude of analysis increment as in the U.K Mes.

4.4 Ob types assimilated

1. ATOVS (AMSU but not HIRS).
2. Aircraft (AIREPS, AMDARS).
3. Scatwind (SeaWinds scatterometer).
4. Satwind (METEOSAT-5, METEOSAT-7 [IR,WV,VIS], GOES-12 [IR]).
5. Sonde (TEMP, PILOT, DROPSONDE).
6. SSM/I (10m Windspeed).
7. Synops (Surface pressure, Wind, Temperature, RH, Visibility).
8. Drifting buoys
9. Wind profilers

4.5 Thinning

Observation Type	Horizontal Thinning
ATOVS	0.4 degree
SSM/I	125 km
Scatwind	46 km
Satwind	2 degree (100hPa in the vertical)

4.6 Data cutoff

QY00 = 275 mins
QY06 = 190 mins
QY12 = 265 mins
QY18 = 205 mins

4.7 Varobs plots and stats

A Parallel Suite was run by Operations in April 2003 and the following Varobs data were taken from the trial on 09/04/03 and 10/04/03.

ATOVS data represent the largest data volumes. All data (AMSU-A and AMSU-B) for a 06Z run (Figure 5) and the AMSU-B data at low levels (channel 20) are plotted (Figure 6). This channel is plotted because there can be the more rejection of data at this level than at higher levels (channels 18 and 19) and so it is interesting to see how many data are assimilated.

ATOVS data for an 18Z run (Figure 7) and AMSUB channel 20 (Figure 8) are plotted. The different geographical location of NOAA-16 and NOAA-17 swaths compared to 06Z is clear. Note the lack of ATOVS data assimilated over the high ground of Greenland and the Alps and the lack of AMSUB data assimilated over land (as one would expect).

Aircraft data for an 18z run (Figure 9) show the large coverage over Europe and N.America and also the routes across the Atlantic. The vertical lines correspond to those observations taken every 5 degrees of longitude.

Surface data for an 18z run (Figure 10) show the dense coverage over Europe.

Scatwind data show a surprisingly small number of observations. Typically from 35000 obs extracted and processed in the OPS, 25000 have a prior rejection leaving 10000 obs. There is a thinning applied which removes one in four obs leaving 2500. Data for 06z (Figure 11) and 18z (Figure 12) show the different geographical locations of the swaths at different times. Consequently some runs have more data rejected due to swaths passing over land.

Satwind data show a difference in data volumes between 06z (Figure 13) and 18z (Figure 14) when there are one and a half times as many observations assimilated.

SSMI data show an even larger difference in data volumes between 06z (Figure 15) and 18z (Figure 16) when there are six times as many observations assimilated.

Varobs plots reveal some interesting variations between runs in the number and location of observations assimilated. Sonde obs for example show a marked difference between 12z (Figure 17) and 18z (Figure 18) due to many locations launching sondes just twice a day at 00z and 12z.

Figure 5: Varobs plot of ATOVS 06z (All data) 33647 obs

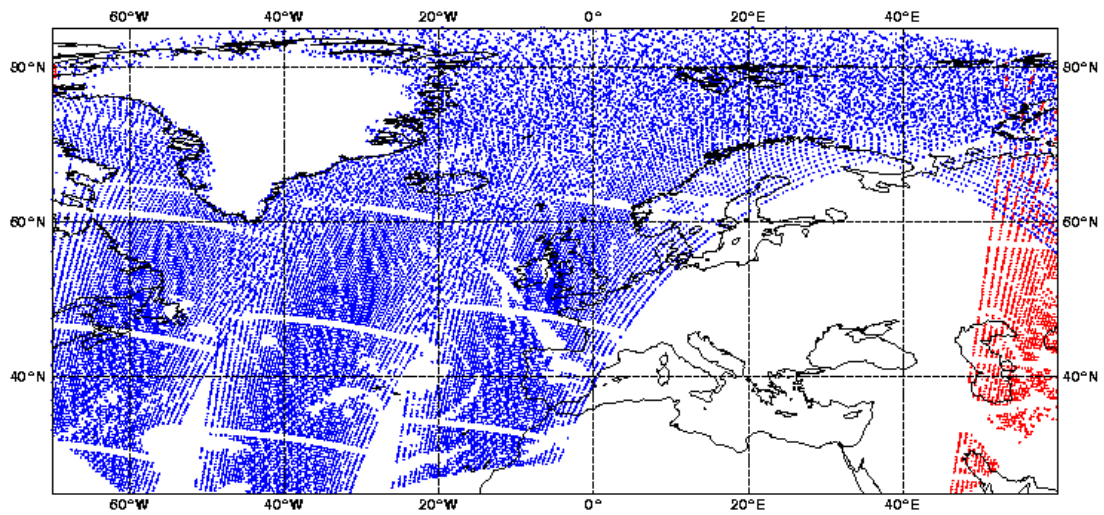


Figure 6: Varobs plot of ATOVS 06z (AMSUB channel 20) 5586 obs

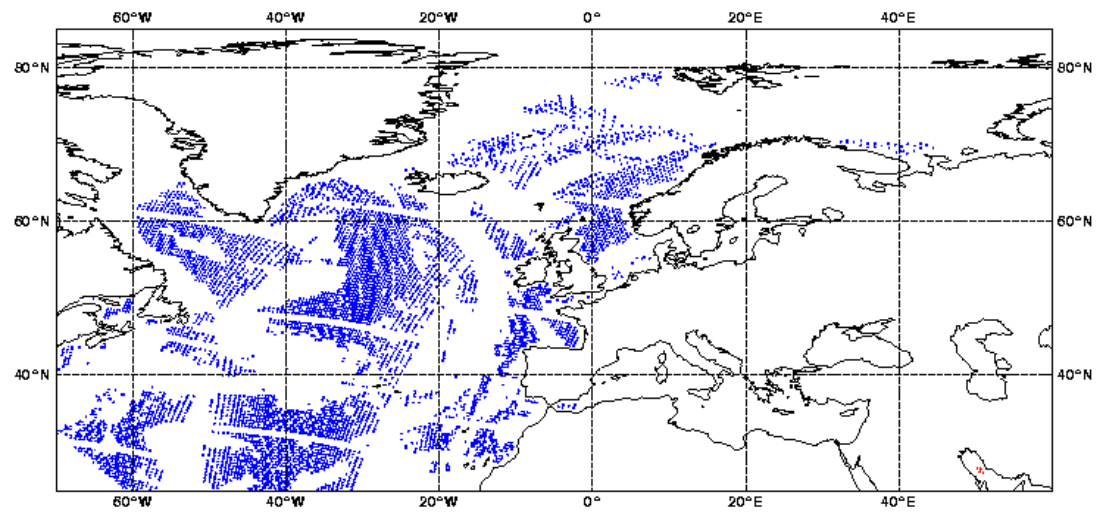


Figure 7: Varobs plot of ATOVS 18z (All data) 40364 obs

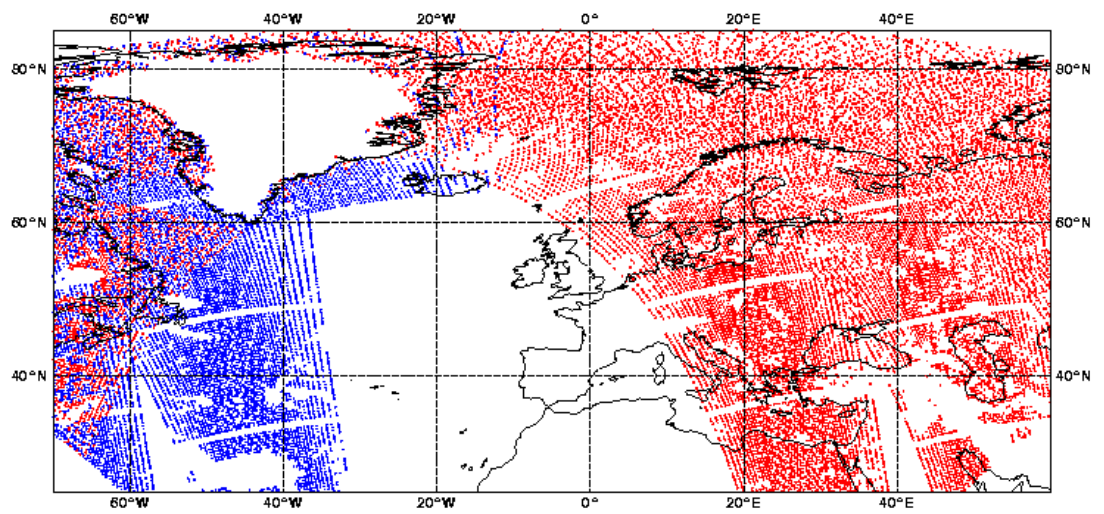


Figure 8: Varobs plot of ATOVS 18z (AMSUB channel 20) NOAA-16 (blue) and NOAA-17 (red) 3835 obs

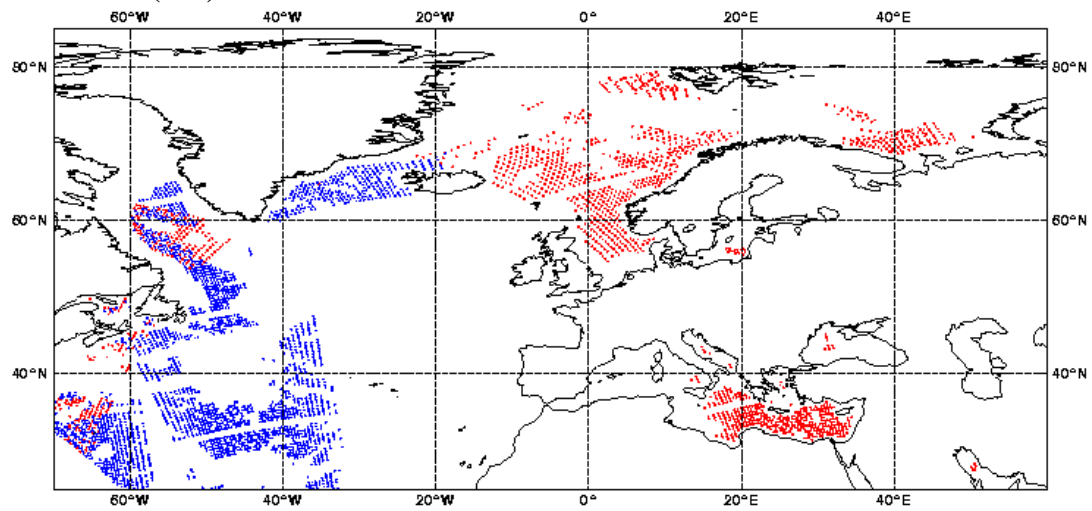


Figure 9: Varobs plot of AIRCRAFT 18z 11105 obs

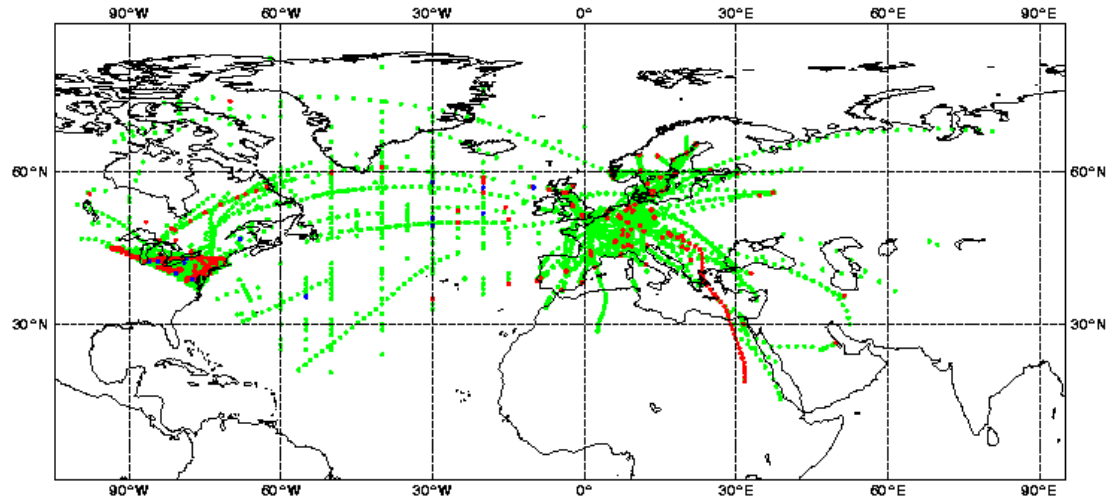


Figure 10: Varobs plot of SURFACE 18z 5102 obs

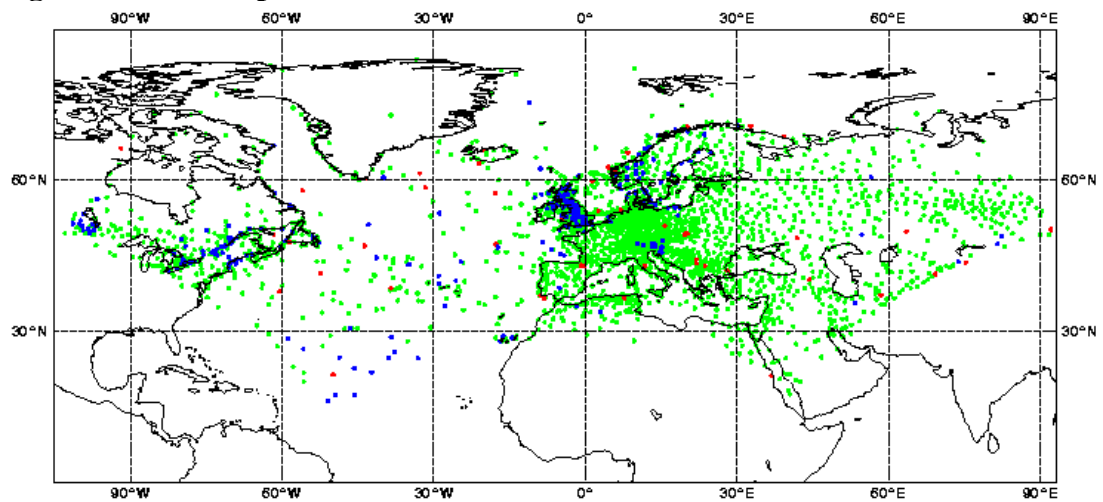


Figure 11: Varobs plot of SCATWIND 06z 2032 obs

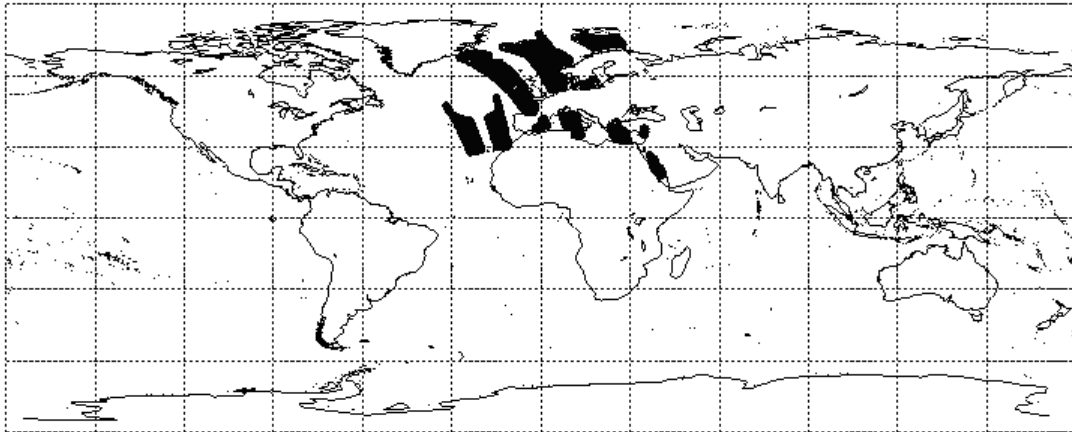


Figure 12: Varobs plot of SCATWIND 18z 692 obs

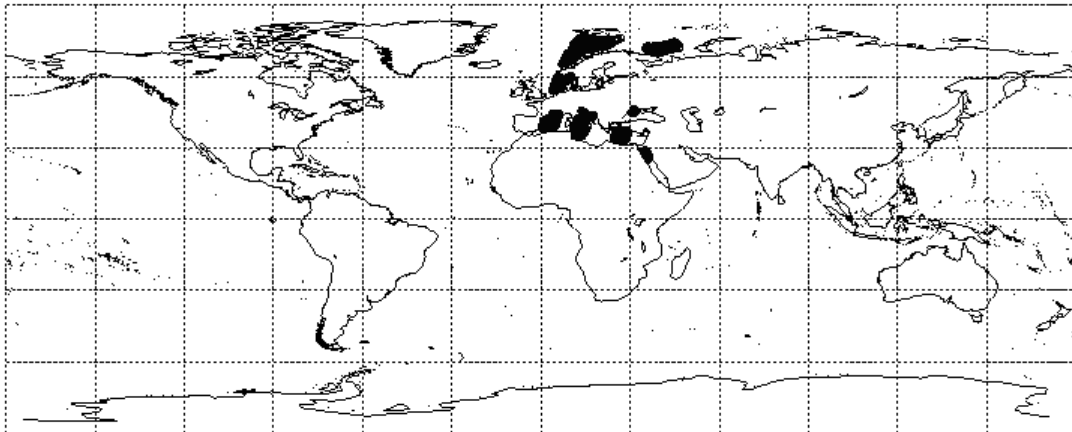


Figure 13: Varobs plot of SATWIND 06z 799 obs

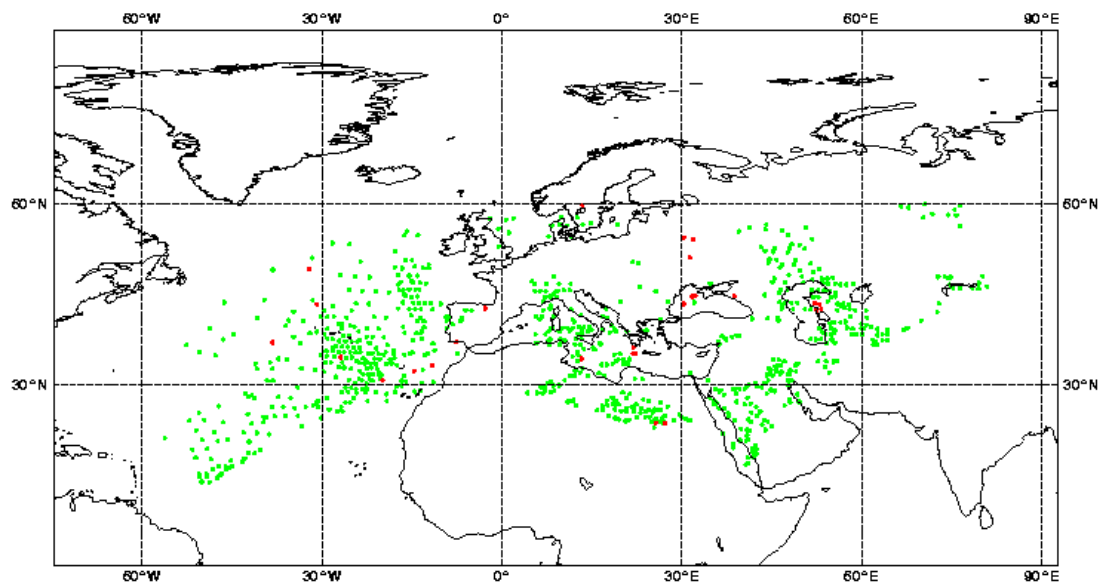


Figure 14: Varobs plot of SATWIND 18z 1203 obs

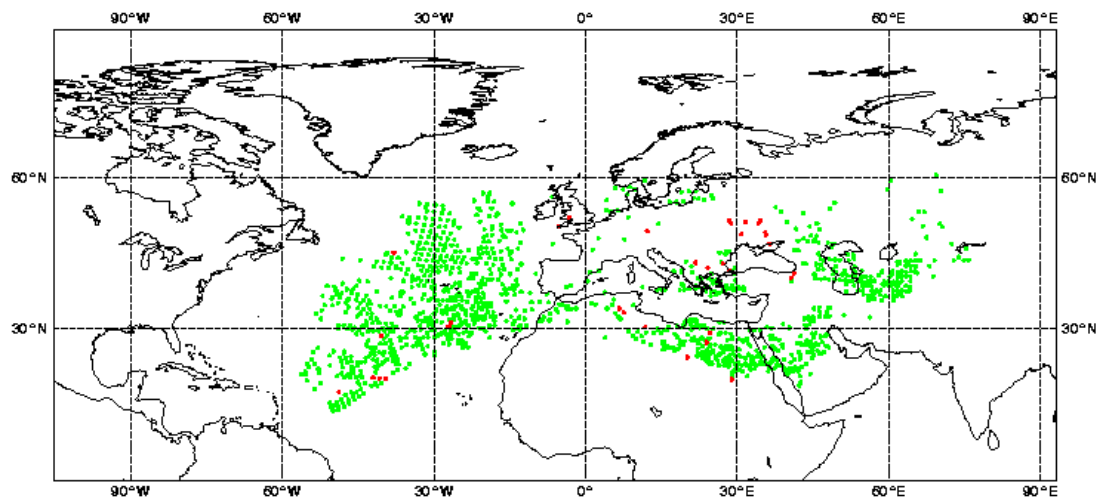


Figure 15: Varobs plot of SSMI 06z 109 obs

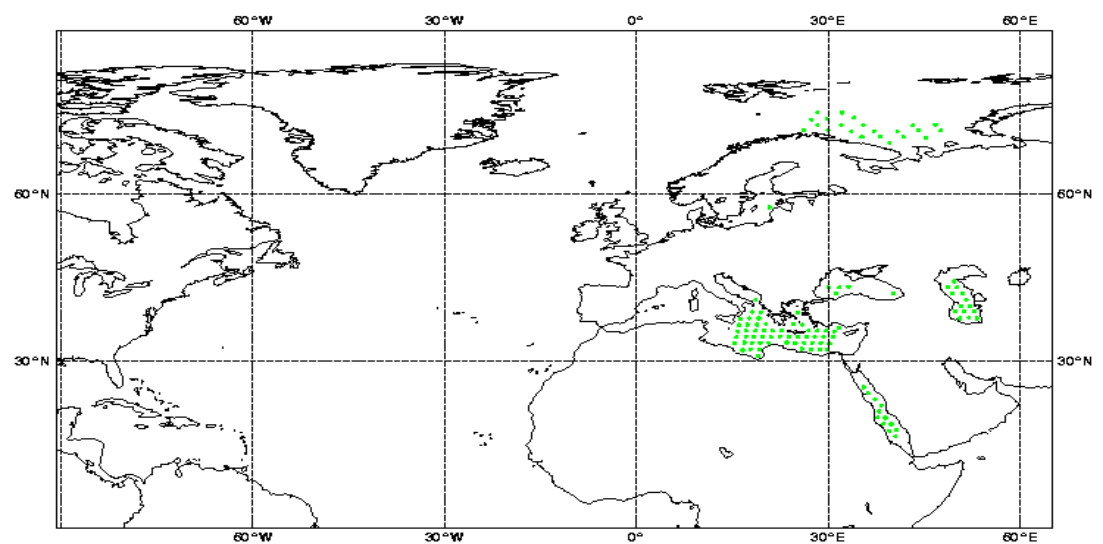


Figure 16: Varobs plot of SSMI 18z 659 obs

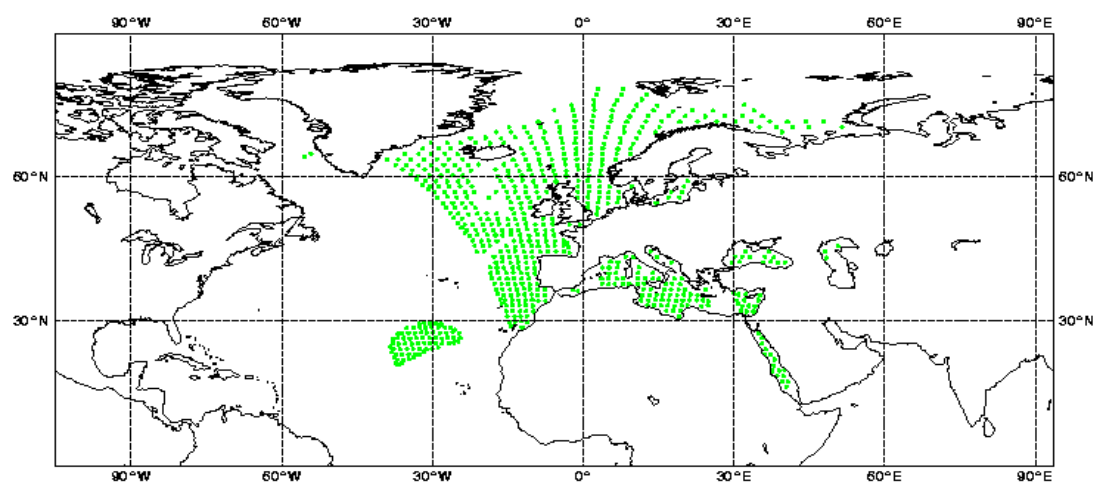


Figure 17: Varobs plot of SONDE 12z 313 obs

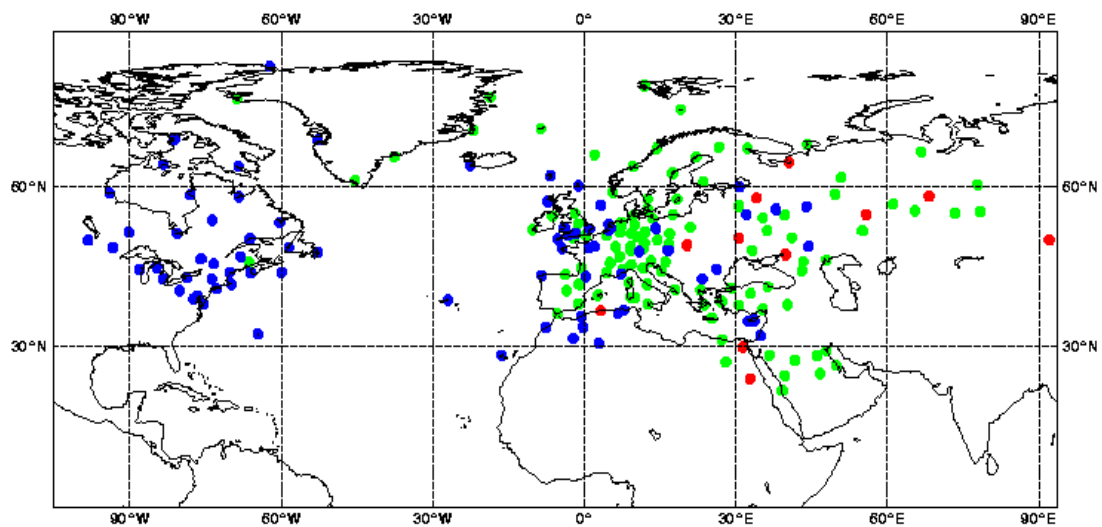
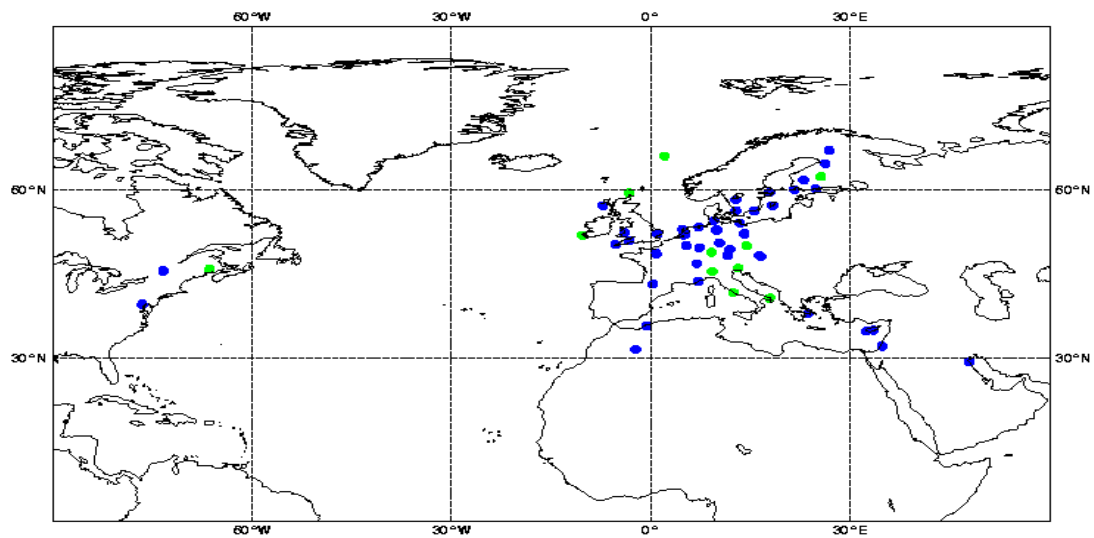


Figure 18: Varobs plot of SONDE 18z 158 obs



Varobs stats on 09/04/03 and 10/04/03

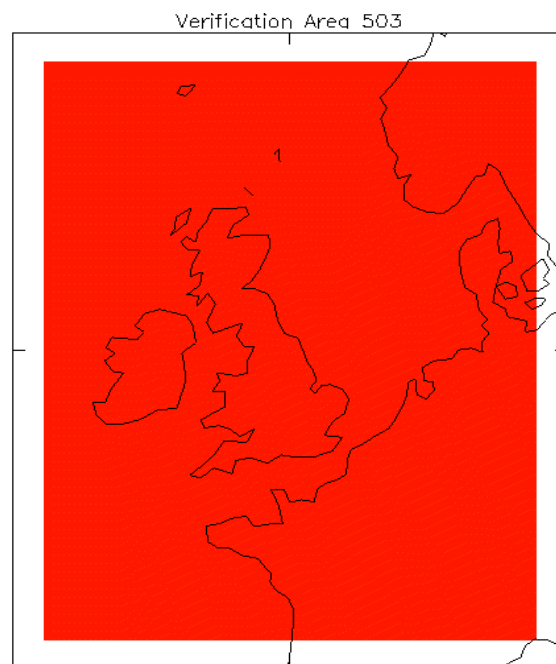
Ob type	No. of obs	Not flagged	Flagged	Missing
ATOVS 06z	33647	33647	0	0
ATOVS 18z	40364	40364	0	0
AMSUB 06z	5586	5586	0	0
AMSUB 18z	3835	3835	0	0
Aircraft 18z	11105	10625	466	14
Surface 06z	5155	4553	64	538
Surface 18z	5102	4520	72	510

Scatwind 06z	2032	2032	0	0
Scatwind 18z	692	692	0	0
Satwind 06z	799	772	27	0
Satwind 18z	1203	1170	33	0
SSMI 06z	109	109	0	0
SSMI 18z	659	659	0	0
Sonde 12z U	313	144	12	157
Sonde 18z T	158	13	0	145

4.8 Performance of the Parallel Trial

A Parallel trial was carried out in April 2003. Verification was performed over two areas. Verification Area 503 (Figure 19) covers the reduced (by eight points around the rim) Mesoscale Model Area while Area 512 covers the reduced NAE Area.

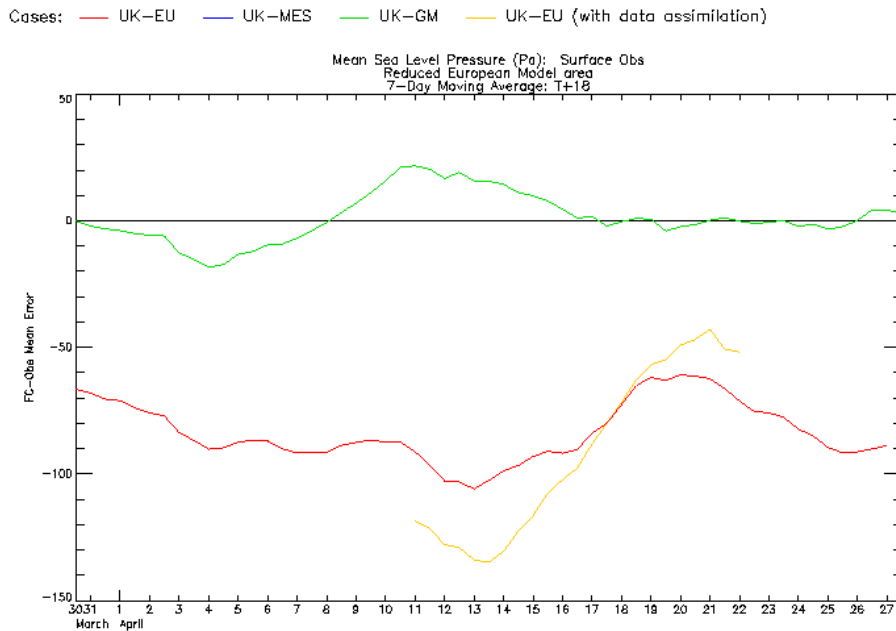
Figure 19: Verification Area 503



- Greater 500hPa height RMSE than the Global Model at all forecast ranges over both areas.
- Greater 850hPa wind RMS Vector Error than the Global Model at all forecast ranges over both areas.
- Smaller relative humidity moist bias and RMSE compared to the Global Model at all forecast ranges over both areas

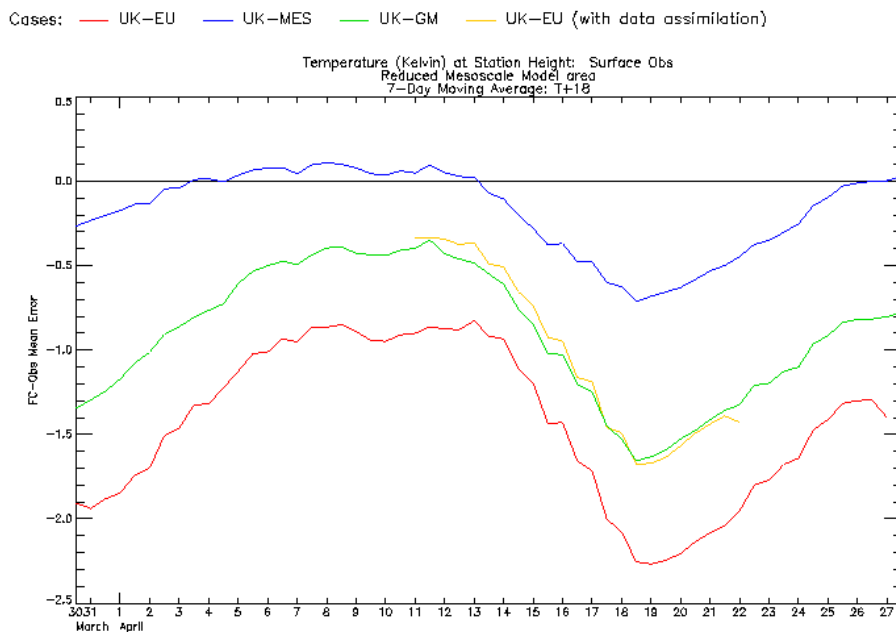
- Larger PMSL negative bias (Figure 20) and RMSE than the Global or UK Mes at all forecast ranges over both areas

Figure 20: PMSL Bias at T+18 over Area 512. Operational NAE (red), NAE with DA (yellow) and Global (green).



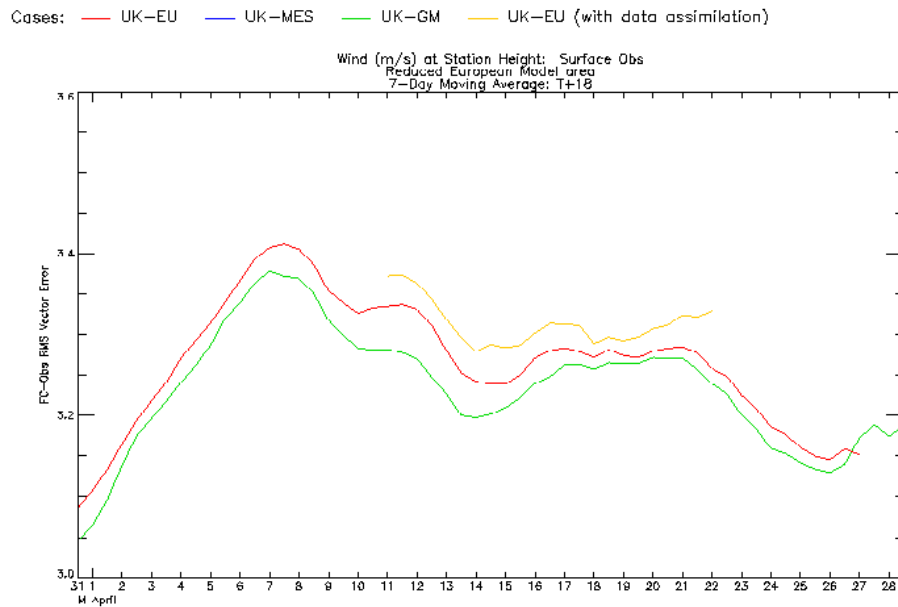
- Smaller temperature cold bias (Figure 21) and RMSE than the Global Model from T+6 to T+30 over both areas. Skill scores worse due to the small RMS error of the persistence.

Figure 21: 1.5m temperature bias at T+18 over Area 503. Operational NAE (red), NAE with DA (yellow), U.K Mes (blue) and Global (green).



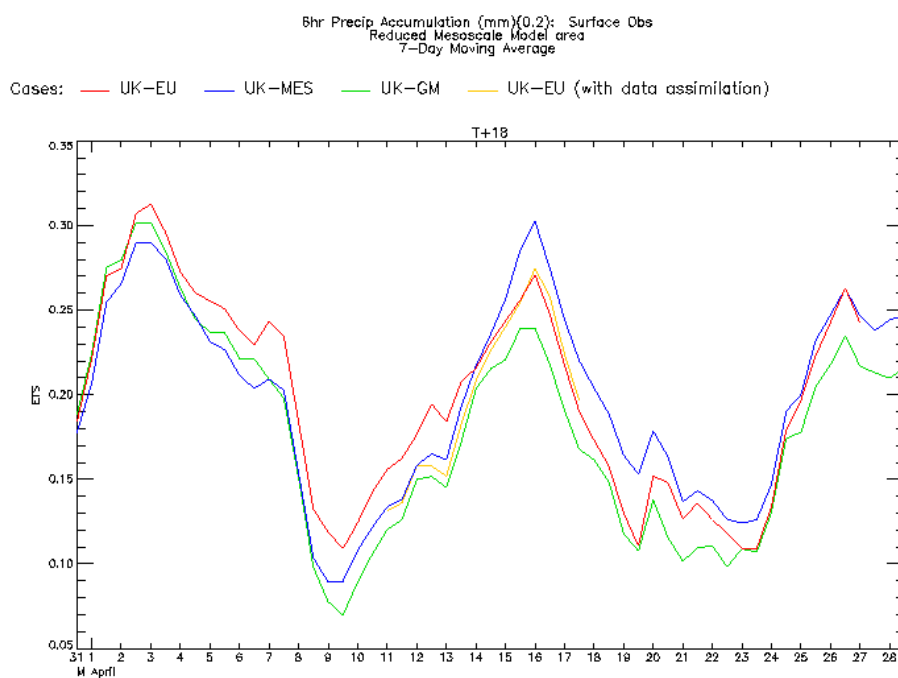
- Larger positive wind speed bias and RMS Vector Error (Figure 22) than the Global Model at all forecast ranges over area 512.

Figure 22: 10m wind RMS Vector Error at T+18 over Area 512. Operational NAE (red), NAE with DA (yellow) and Global (green).



- Greater 6 hour Precipitation Accumulation ETS than the Global Model at both the 0.2mm and 1.0mm thresholds over Area 503 (Figure 23) and also at the 0.2mm threshold over area 512. The ETS was comparable at the 4.0mm threshold over Area 512.

Figure 23: Precipitation ETS at T+18 over Area 503. Operational NAE (red), NAE with DA (yellow), U.K Mes (blue) and Global (green).



- Greater visibility ETS than the Global Model at the 5000m threshold over area 503.
- Lower cloud cover and cloud base height ETS than those from the UK Mesoscale Model over area 503.

4.9 Norwegian Lateral Boundary Conditions (LBC's)

Collaboration between Met. No (the Norwegian Met Service) and the Met Office started in 2002. The UM was installed at their HQ in Oslo and from the 15/08/2003, a quasi-operational UM 3km run has been run over Southern Norway forced by NAE LBC's.

5) Upgrade to UM5.5 (03/12/2003)

The upgrade from UM5.3 to UM5.5 brought the NAE into line with the latest science options and meant that for the first time, the NAE shared the same executable as all the UM limited area configurations. It was also an important step in preparation for running on the NEC supercomputer as UM5.5 formed the basis for UM6.0.

5.1 Package details

- Upgrade of UM version from UM5.3 to UM5.5.
- Upgrade of convection from Version 3C to 4A (formerly known as CMODS).
- Inclusion of targeted diffusion of moisture (together with a steep slope detection).
- A number of cloud formulation changes (as used in the UK Mes model).
- Inclusion of Shear-dominated boundary layer type.
- Upgrade of OPS build from 12.7 to 20.1.
- Upgrade of VAR build from 19.4 to 20.1
- Upgrade of SURF build from 14.4 to 15.1

5.2 Grid Point Storms

There were a number of operational failures in all of the limited area models throughout the Summer of 2003 as a result of grid point storms (see section 4.3). Investigations revealed that the targeted diffusion of moisture was not being applied as previously thought. The UM5.5 package corrected this error and tests in other limited area configurations of the UM showed the UM5.5 package to be much more stable than UM5.3.

5.3 Objective Verification

A real time Parallel Trial was carried out with verification results available for the period 10th September 2003 to 21st October 2003.

The results for Verification Area 512 show the UM5.5 package performs better than the operational for all variables. Figure 24 shows improvements to Surface Visibility, 6 hourly Precipitation Accumulation, Total Cloud Amount, Surface Temperature and Surface Wind at all forecast ranges and virtually all ETS thresholds.

Figure 24: Objective Verification results for Verification Area 512 (Reduced European Model Area).

A modified version of the UK Index Impact software has been used to produce these results. The calculations use a minimum of 24 values.

VerProg_UKIndexImpact

Total number of days = 42

From 20030910 to 20031021

Validity Times: 0 600 1200 1800

Area Code: 512

Cntl ARD Path: /u/m08/t08ut/scs/run/TestSuite2002/Euro/ARD_EU

Test ARD Path: /u/m11/data3/t11bu/scs/MY/run/eurovar/opdaily/datawver/ARD_EU

Cntl Exp Id: UK-EU

Test Exp Id: TE-EU

Parameter Details				Num Values				Control Data					Test Data					Test-Cntl
Field	Thres	Fc Range	Wt	0Z	6Z	12Z	18Z	A	B	C	D	ETS	A	B	C	D	ETS	Wted ETS Diff
Surf Vis	200.00	T+6	2	15	0	17	0	18	125	272	59171	0.042	32	224	257	59069	0.060	0.031
		T+12	2	0	16	0	18	48	336	480	66144	0.052	65	496	463	65967	0.059	0.012
		T+18	2	15	0	9	0	25	203	224	42749	0.053	27	280	221	42669	0.048	-0.008
		T+24	2	0	16	0	14	81	742	430	57901	0.059	99	904	412	57722	0.064	0.008
	1000.00	T+6	2	15	0	17	0	70	245	741	58530	0.062	118	387	692	58385	0.093	0.051
		T+12	2	0	16	0	18	164	685	1252	64907	0.070	210	707	1206	64868	0.091	0.034
		T+18	2	15	0	9	0	77	550	607	41967	0.055	101	495	582	42019	0.078	0.039
		T+24	2	0	16	0	14	232	1415	1122	56385	0.071	282	1159	1072	56624	0.100	0.049
	5000.00	T+6	2	15	0	17	0	1643	3490	3398	51055	0.149	1553	2365	3484	52180	0.173	0.039
		T+12	2	0	16	0	18	2858	7987	4509	51654	0.118	2222	4186	5141	55442	0.140	0.037
		T+18	2	15	0	9	0	1763	5777	2190	33471	0.119	1284	2946	2665	36302	0.138	0.032
		T+24	2	0	16	0	14	3149	9943	3388	42674	0.113	2124	4630	4409	47974	0.132	0.032
6 hr Precip Accum	0.20	T+6	2	15	0	17	0	31366	1788	5215	5328	0.340	31995	1754	4693	5362	0.366	0.044
		T+12	2	0	16	0	18	41668	2384	5399	4699	0.303	30729	1786	4019	3989	0.329	0.044
		T+18	2	15	0	9	0	23792	1710	3079	3641	0.345	23627	1517	3231	3834	0.359	0.023
		T+24	2	0	16	0	14	36128	2391	4414	3432	0.264	24735	1545	3488	2970	0.292	0.047
	1.00	T+6	2	15	0	17	0	35603	1241	3782	3071	0.323	36372	1282	3120	3030	0.355	0.054
		T+12	2	0	16	0	18	46618	1783	3037	2712	0.317	34640	1409	2208	2266	0.340	0.038
		T+18	2	15	0	9	0	26836	1220	2139	2027	0.324	26880	1180	2082	2067	0.336	0.020
		T+24	2	0	16	0	14	40049	1786	2652	1878	0.255	27941	1270	1953	1574	0.282	0.045
	4.00	T+6	2	15	0	17	0	39883	762	1891	1161	0.279	40473	792	1408	1131	0.317	0.063
		T+12	2	0	16	0	18	51107	975	1223	845	0.261	38140	797	917	669	0.263	0.004
		T+18	2	15	0	9	0	29877	749	908	688	0.271	29920	742	852	695	0.282	0.018
		T+24	2	0	16	0	14	43739	940	1136	550	0.193	30796	660	806	476	0.227	0.058

Parameter Details			Num Values					Control Data					Test Data					Test-Cntl
Field	Thres	Fc Range	Wt	0Z	6Z	12Z	18Z	A	B	C	D	ETS	A	B	C	D	ETS	Wted ETS Diff
Total Cloud Amount	0.31	T+6	2	15	0	17	0	12568	8373	4168	22756	0.295	12429	6600	4307	24528	0.346	0.085
		T+12	2	0	16	0	18	14323	9007	5105	26280	0.300	14483	6942	4942	28331	0.366	0.111
		T+18	2	15	0	9	0	9543	5462	3672	15374	0.289	9140	4262	4075	16573	0.321	0.052
		T+24	2	0	16	0	14	12117	7810	5263	23056	0.274	12205	5979	5172	24873	0.336	0.104
	0.56	T+6	2	15	0	17	0	17910	8635	4786	16534	0.284	17402	6647	5295	18520	0.334	0.084
		T+12	2	0	16	0	18	20167	9662	5857	19029	0.278	19800	6984	6216	21698	0.348	0.117
		T+18	2	15	0	9	0	13263	5659	3954	11175	0.278	12671	4301	4547	12531	0.316	0.064
		T+24	2	0	16	0	14	17152	8461	6032	16601	0.251	16856	6116	6320	18937	0.319	0.114
	0.81	T+6	2	15	0	17	0	25742	7223	5413	9487	0.253	24766	5195	6389	11514	0.312	0.099
		T+12	2	0	16	0	18	28727	8710	6518	10760	0.232	27552	5898	7684	13564	0.307	0.123
		T+18	2	15	0	9	0	18714	4813	4117	6407	0.248	17627	3415	5204	7804	0.290	0.070
		T+24	2	0	16	0	14	24601	7656	6664	9325	0.205	23611	5225	7645	11748	0.277	0.119

Parameter Details			Num Values				Control Data			Test Data			Test - Control	
Field	Fc Range	Wt	0Z	6Z	12Z	18Z	Fc RMS	Per RMS	Skill	Fc RMS	Per RMS	Skill	Fc RMS Diff (%)	Wted Skill Diff
Surf Temp	T+6	6	15	0	16	0	2.291			2.047			-10.629	
	T+12	6	0	16	0	18	2.448			2.199			-10.191	
	T+18	6	15	0	9	0	2.269			2.120			-6.602	
	T+24	6	0	16	0	14	2.456			2.244			-8.608	
Surf Wind	T+6	6	15	0	16	0	3.244			3.071			-5.351	
	T+12	6	0	16	0	18	3.438			3.165			-7.961	
	T+18	6	15	0	9	0	3.495			3.308			-5.342	
	T+24	6	0	16	0	14	3.845			3.396			-11.681	

Parameter	Control Data	Test Data	Test - Control
	Mean ETS	Mean ETS	Wted ETS Diff
Surface Visibility	0.080	0.098	0.357
6 hr Precip Accum	0.290	0.312	0.457
Total Cloud Amount	0.266	0.323	1.143

Figure 25: Objective Verification results for Verification Area 2103 (WMO Block 3 stations).

A modified version of the UK Index Impact software has been used to produce these results. The calculations use a minimum of 24 values.

Parameter Details			Num Values				Control Data			Test Data			Test - Control	
Field	Fc Range	Wt	0Z	6Z	12Z	18Z	Fc RMS	Per RMS	Skill	Fc RMS	Per RMS	Skill	Fc RMS Diff (%)	Wted Skill Diff
Surf Temp	T+6	6	15	0	16	0	1.799			1.794			-0.274	
	T+12	6	0	16	0	18	2.155			1.978			-8.224	
	T+18	6	15	0	9	0	1.883			1.867			-0.855	
	T+24	6	0	16	0	14	2.228			1.967			-11.713	
Surf Wind	T+6	6	15	0	16	0	2.846			2.775			-2.503	
	T+12	6	0	16	0	18	3.208			2.896			-9.726	
	T+18	6	15	0	9	0	3.331			3.164			-5.000	
	T+24	6	0	16	0	14	3.855			3.104			-19.469	

Parameter	Control Data	Test Data	Test - Control
	Mean ETS	Mean ETS	Wted ETS Diff
Surface Visibility	0.063	0.066	0.051
6 hr Precip Accum	0.250	0.294	0.865
Total Cloud Amount	0.196	0.263	1.329

Figure 25 shows the results for Area 2103 (WMO Block 03 stations). It can be seen that the superior performance also holds over the U.K region and the improvement to the cloud and precipitation ETS has strengthened compared to the Area 512 results. On the other hand, there now appears to be a more neutral impact on Visibility, Light Precipitation (0.20mm threshold) and Surface Temperature at T+6.

The negative cloud amount Bias and the RMSE for both Areas 512 and 2103 have been reduced. The improvement is most probably due to the changes in the cloud formulation. Relative humidity RMSE has been decreased in the UM5.5 run.

The positive wind bias and the RMS Vector Error for both Areas 512 and 2103 have been reduced.

The negative temperature Bias for both Areas 512 and 2103 against forecast range has worsened although the RMSE has decreased.

5.4) Subjective verification

The UM5.3 model suffered two particularly poor periods of performance centred around 11/12th September (ex-Hurricane Fabian) and 26/27th September. The UM5.5 trial performed better than the operational as can be seen in Figures 26 -28.

Figure 26 shows the Global Model verifying analysis at 18z on 27/09/2003 with a high pressure centred over the Western Atlantic (1033mb) and a low of 1000mb to its southwest and a low of 1014mb to its southeast of 1014mb. The operational model has a much deeper system with a central pressure of around 980mb at 21z on 27/09/2003 (Figure 27). Meanwhile the T+15 UM5.5 run valid at the same time (Figure 28) has a central pressure of around 1012 mb and thus verifies much better.

Figure 26: Global Model verifying analysis showing PMSL at 18z on 27/09/2003

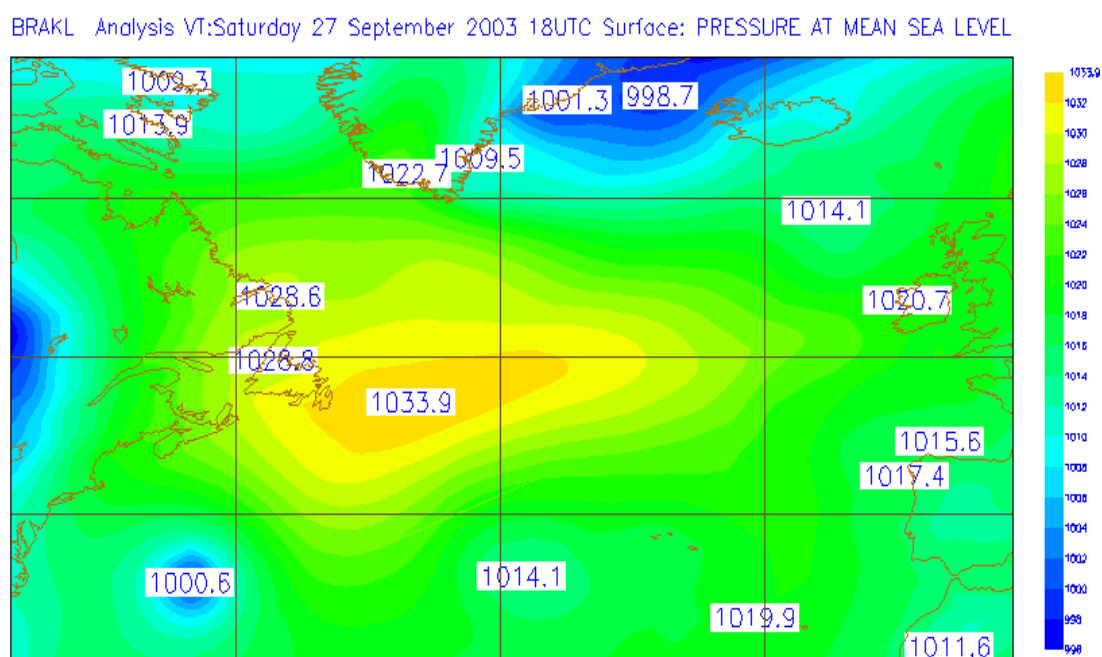


Figure 27: Operational model PMSL and precipitation at T+15 on 27/09/2003

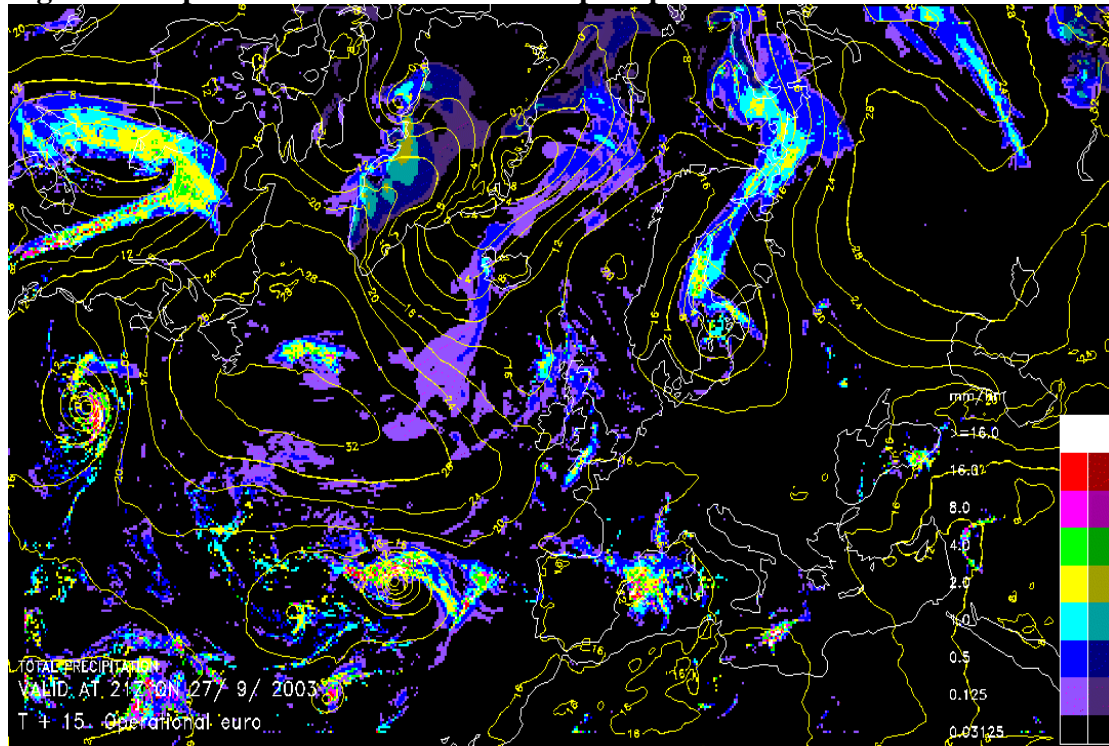
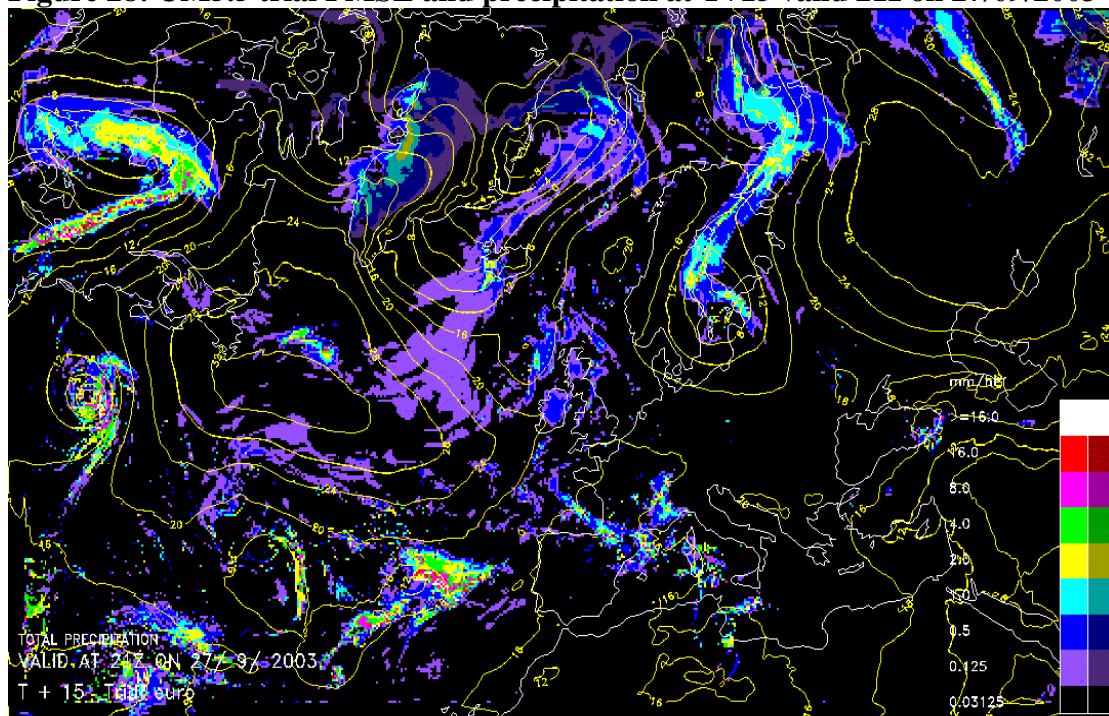


Figure 28: UM5.5 trial PMSL and precipitation at T+15 valid 21z on 27/09/2003



6) Introduction of a new orography ancillary (16/12/2003)

There were four operational failures between October and December 2003 (NMC problem 200) that were caused by very low temperatures (40K) over Greenland. Part of Baffin Island in Northern Canada also had unrealistically low temperatures. Quite separately, this problem had also been noted in high resolution (2km) UM forecasts of MAP case studies over the Alps (where theta had gone to zero). In all cases the

cooling occurred in steep sided valleys or hollows where a cold pool of air was able to stagnate and undergo runaway cooling (Figure 29).

Figure 29: 4 delta x orography over Baffin Island, Canada

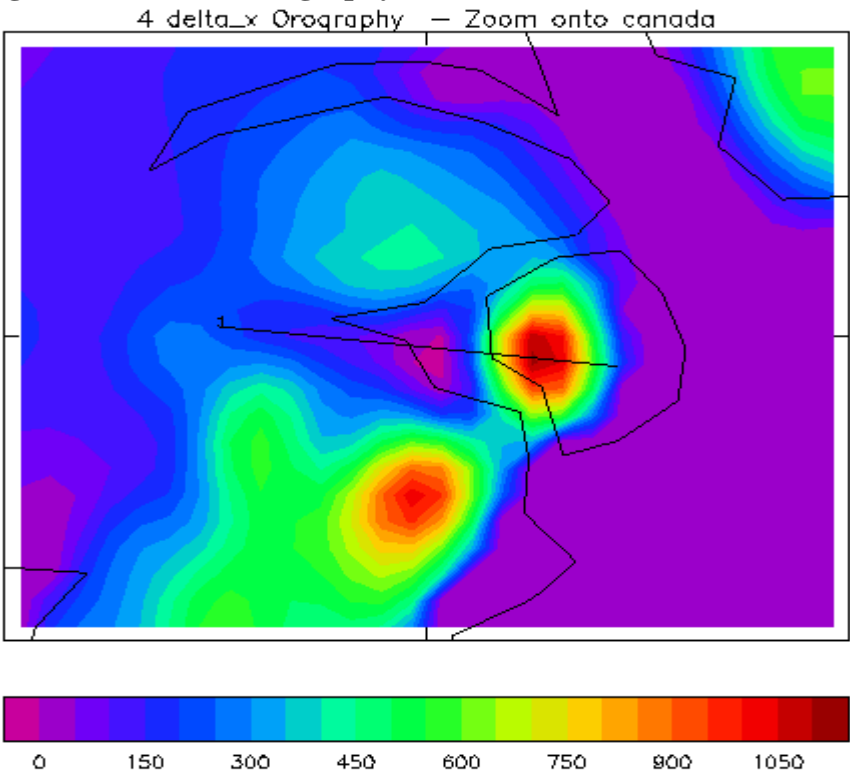
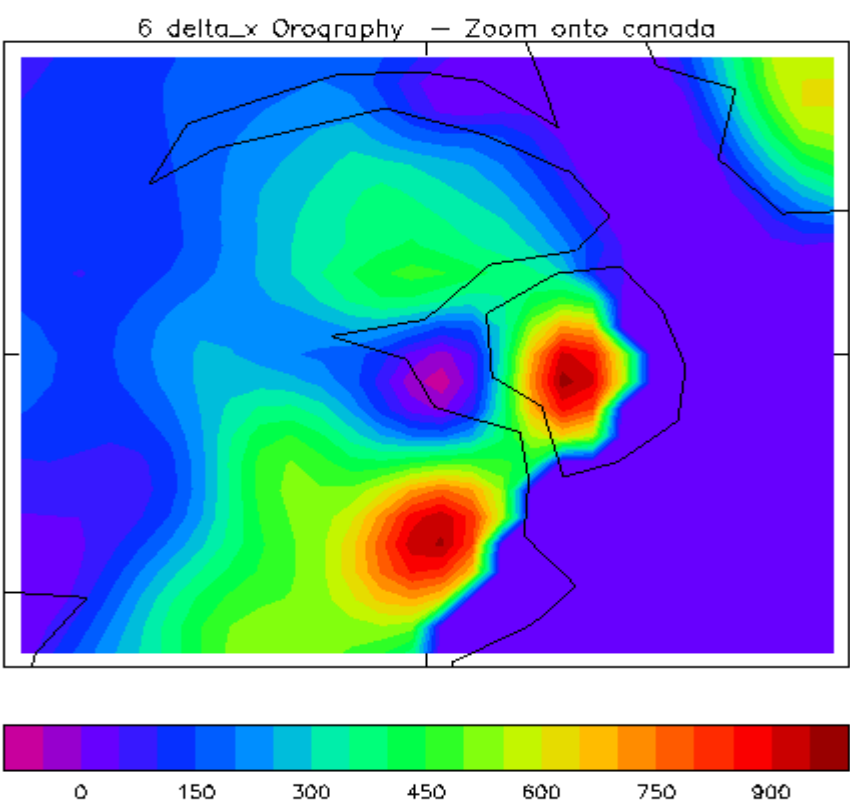


Figure 30: 6 delta x orography over Baffin Island, Canada



A project was initiated to investigate the cause. However a solution was required urgently and so a revised orography ancillary with extra smoothing (6 delta x) applied everywhere was introduced (Figure 30). Previously the orography had a 4 delta x smoothing.

7) Revision to the Critical Froude Number and Surface Gravity Wave constant (07/01/2004)

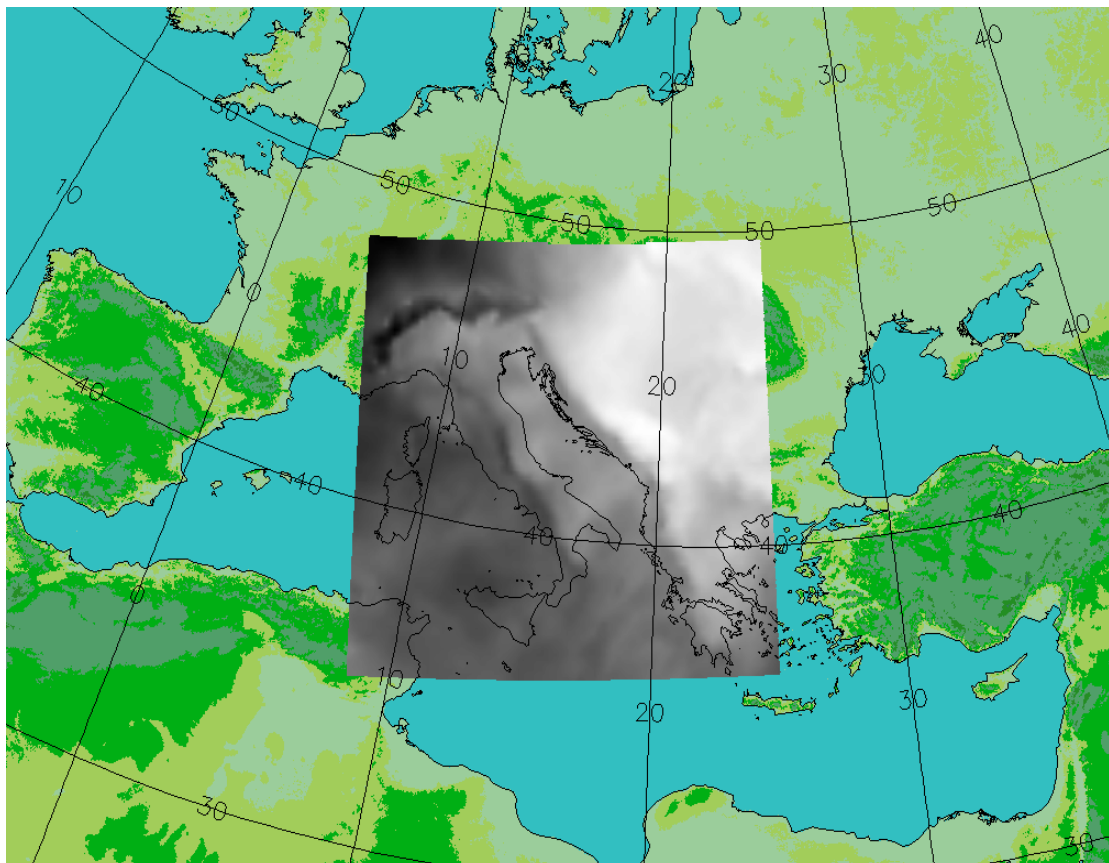
- Critical Froude Number increased from 1.0 to 4.0
- Surface Gravity Wave constant increased from $3.00\text{e}+03$ to $5\text{e}+04$

These two constants were changed from their previous UK Mes values to values felt to be more physically reasonable.

8) Replacement of the Balkans Model (23/03/2004)

The NAE became the source of Balkans products on HORACE (Figure 31) from 23/03/2004 with the Balkans model itself being withdrawn on 30/03/2004.

Figure 31: Balkans Model domain



9) Upgrade to UM6.0 (27/04/2004)

This upgrade involved porting the NAE Operational suite from the Cray T3E supercomputer to the NEC SX6.

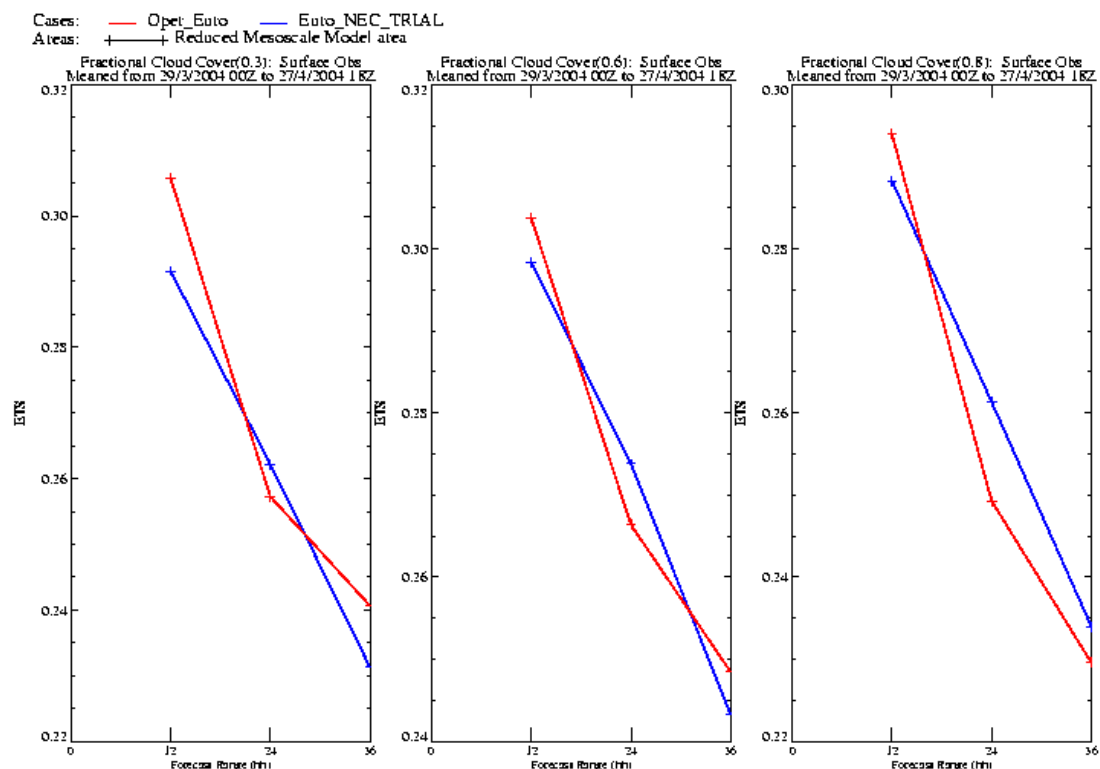
9.1 Package details

- Upgrade of UM version from UM5.5 to UM6.0.
- Extend forecast to T+48. All 4 runs to go to T+48.
- Change Global to output Norwegian lbc's from QG00/06/12/18.
- Various optimisations for running on the NEC
- Upgrade of OPS build from 20.1 to 20.2.
- Upgrade of VAR build from 20.1 to 20.2
- Upgrade of SURF build from 15.1 to 15.2

9.2 Objective Verification

A parallel Trial was run for one month from 29th March 2004 to 27th April 2004. Objective Verification showed little difference in performance between the operational model and the UM6.0 trial (as expected). Figure 32 shows fractional Cloud Cover ETS against lead time over Area 503.

Figure 32: Fractional Cloud Cover ETS against lead time over Area 503. Operational NAE (red) and UM6.0 trial (blue).



10) Data Assimilation and UM upgrade package (22/09/2004)

10.0 Overview

The successful implementation of the Data Assimilation (DA) and UM upgrade package (tested in Parallel Suite 1.0) finally allows the NAE to gain Operational Status. This was given once WGOS had been shown that NAE performance was consistently better than the Global model.

10.1 Data Assimilation Package details

The Data Assimilation changes are the first major changes to the DA system since the introduction of Data Assimilation in August 2003. They give the NAE the same observational input as the UK Mes model and also the same covariance statistics and tuning. These settings are also consistent with the NAE being upgraded to 12km resolution (the same as the UK Mes model) in February 2005.

10.1.1 3hr assimilation cycle

The assimilation cycle in the NAE suite is changed from 6-hourly to 3-hourly, as in the UK Mes suite. This increases the computational cost due to the extra intermediate runs that are required (QY03, QY09, QY15, QY21). The assimilation will remain at half model resolution. Despite the cost increase, the 3-hourly cycle requirement is a necessary one in the development of the model as the main forecast provider for both the UK and the whole NAE area.

The following data cut-offs are applied:

QY00: 2h45 = 165 minutes

QY03: 4h00 = 240 minutes

QY06: 2h35 = 155 minutes

QY09: 4h00 = 240 minutes

QY12: 2h45 = 165 minutes

QY15: 4h00 = 240 minutes

QY18: 2h40 = 160 minutes

QY21: 4h00 = 240 minutes.

10.1.2 AC scheme

Assimilating MOPS cloud and rain data into the NAE model helps achieve consistency with the UK Mes model. Standard UK Nimrod data is used as the quality of the European Nimrod products is not yet well established.

10.1.3 EARS

The globally received ATOVS data (ATOVSG) are replaced with the locally received EARS ATOVS data. These are received more quickly and thus give us more observations before the data cut off. Along with this, the upgrade includes migration to the latest RTTOV-7 forward model and use of high level channels over high land, (these changes bring the NAE into line with the Global model).

Figure 33: ATOVS data coverage for the QY06 run on 01/10/2004

Left Panel: Run with ATOVSG and RTTOV- 5.

Right Panel: Run with EARS and RTTOV-7

Red = NOAA15 and Blue = NOAA16

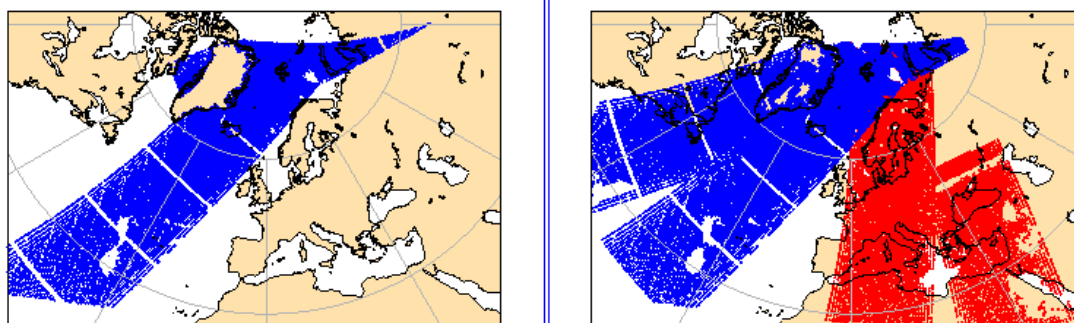


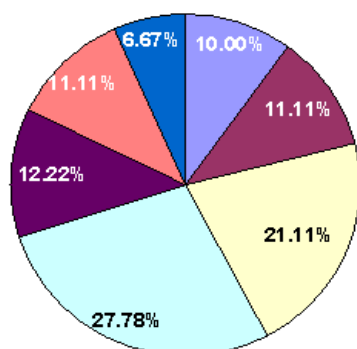
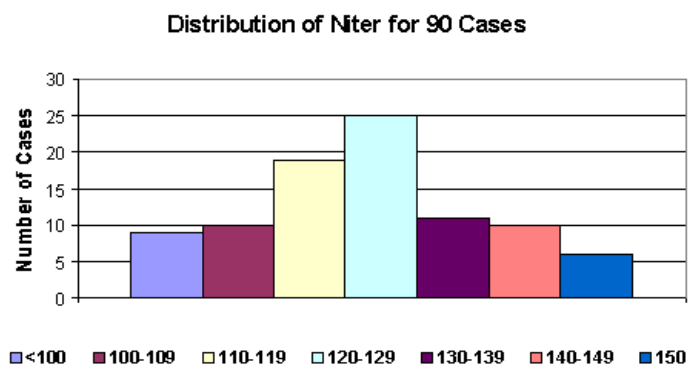
Figure 33 illustrates the extra data assimilated over Greenland (previously rejected due to its elevation) by RTTOV-5 and the extra swaths available due to EARS.

10.1.4 Satellite Winds

Assimilation of satellite winds from rapid scan Meteosat 6 is included in the UK Mes and is also now included in the NAE model. Other minor changes are to remove the restriction of using GOES AMW SatWinds only within the time window -180 to 0 minutes and to use thinning performed for Meteosat data instead.

10.1.5 Revised convergence criteria for analysis

Fig. 34 The distribution of 90 values of the number of iterations (Niter) from the case study VAR runs in test experiment



Optimised settings are employed ($J17_{abs}=1000$, $g_ratio=1.e-08$, $MaxIterations=150$), which terminate the minimisation earlier, but not at the expense of accuracy. The criteria were chosen to achieve a similar degree of convergence as the UK Mes model, without unnecessarily iterations.

Fig. 34 illustrates the distribution of 90 Niter values from a test experiment with the 15 case studies. It is shown that about half of the VAR runs required 110-129 iterations to converge, whereas only 6.67% of them reached the new maximum limit of 150 iterations. With the old convergence criteria only 10% of the runs would terminate before the current limit of 100 iterations.

10.1.6 UK Mes covariance statistics

Several attempts have been made to optimise the NAE covariance statistics, mainly by tuning the ExtraNormF values, but this didn't give any noticeable improvement. Problems with the quality of the NAE covariance statistics were noticed when they were produced and, without any better data, reversion to the UK Mes statistics is the preferred option. This also paves the way for moving to UK Mes resolution, after which covariance statistics can be re-visited.

10.1.7 Vertical mode truncation

The trailing eigenvectors in the Var vertical transforms contribute little to the total error variance (less than 0.1%), while adding to the computational cost. In the upgrade package only the first 21 of the 38 vertical modes are retained, reducing runtime by about 20% for the VAR analysis step.

10.1.8 Initialisation

IAU remains the initialisation scheme in the upgrade, but modified to be compatible with the 3-hourly assimilation cycle. The IAU insertion period and settings were chosen to be identical to the UK Mes model.

10.2. Preliminary Results from Data Assimilation case studies

The first part of the upgrade assessment includes case study investigations, which test the impact of individual components or a combination of components on the forecast, across a range of weather conditions. A set of 15 cases in the period Oct 2002 – Dec 2003 was chosen. It includes 12 cases with a variety of weather conditions over the UK as recommended by WGOS guidance and 3 cases of interesting weather over Europe. Each study includes two 36-hr forecasts separated by 12 hours, and run off 06 and 18 UTC data times. The experiments performed are summarised in Table 1.

Table 1. The experiments carried out with the set of case studies. The test experiments do not include EARS data assimilation (ATOVSG used instead), but all include the revised convergence criteria, SatWinds and vertical mode truncation

Type	Experiment ID	Description
control (3hr cycle)	control	control (as operational)
test (6hr cycle)	testcld	MOPS cloud
test (6hr cycle)	testnoac	No MOPS assimilation
test (6hr cycle)	testuk	UK CovStats + MOPS cloud
test (6hr cycle)	test	UK CovStats + All MOPS (cloud + rain)

Table 2 provides a comparison of the composite total forecast skill of the test experiments relative to the control for the 15 cases. The first experiment (testcld), with MOPS cloud and *with NAE covariance statistics* compared poorly to the control. The cases were rerun with MOPS cloud removed (testnoac). This gave a small improvement. Since the signal was small and no definite conclusions can be drawn from a limited number of case studies, also given that previous studies have established MOPS cloud can have positive impact in certain cases, the MOPS cloud is included in the upgrade package. Fig. 35 shows the relative impact of the cloud data on individual components of the UK index.

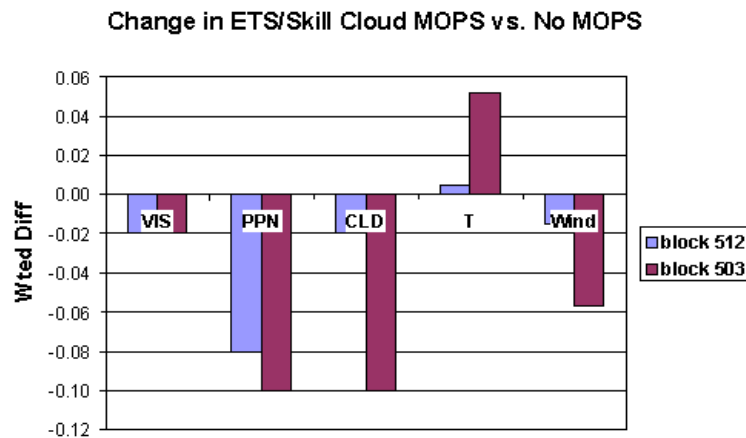
Table 2. Summary of the composite total skill score differences (%) for test experiments relative to the control in blocks 512 (NAE area) and 503 (UK Mes area)

Experiment	Block 512	Block 503
testcld	-2.28	-3.66
testnoac	-2.05	-3.25
testuk	0.09	-0.84
test	0.02	-0.63

Experiment testuk included the MOPS cloud data and replaced the NAE covariance statistics with the *operational UK Mes statistics*, together with associated tunings for ExtraNormF and horizontal correlation length scales. This changed the results significantly. The signal is much smaller and mixed (Table 2), close to neutral in block 512 and negative but small in block 503. These findings favour the use of the UK CovStats and so these are included in the final package.

The impact of LHN was tested separately, in a UK Mes real time trial which ran for 3-4 months. It is assumed that the conclusions from this trial can be extended to the NAE. The trial showed that LHN had a neutral impact on the forecast. As LHN has been found to give an improvement in several previous studies and to give consistency with the UK Mes model, it is included in the upgrade package.

Fig. 35 A comparison between experiments testeld and testnoac that illustrates the change in ETS for visibility, 6hr precipitation accumulation and cloud amount and in the skill scores for temperature and wind when cloud assimilation is included.



Total Weighted Score (Cloud MOPS – No MOPS)

BLOCK 512: -0.29%

BLOCK 503: -0.48%

10.3. UM Package Details

Three UM changes form the UM component of the DA/UM upgrade package.

- A revised orography ancillary file
- Surface gravity wave constant set to 1E+05
- L_MURK_RAD set to false

Their purpose is to stop failures occurring due to the Valley Cooling problem and to reduce the PMSL bias.

10.3.1 Valley Cooling Problem

This problem was described in section 6. The introduction on 16/12/2003 of a revised orography ancillary with extra smoothing (6 delta x) applied everywhere only proved partially successful. Although no further operational failures occurred, the minimum theta in the domain still reached an unrealistically low 188.6K on 15/02/2004, over Baffin Island in Northern Canada. Therefore a new revised orography ancillary

(Figure 36) with even more smoothing (16 delta x over Baffin Island and 8 delta x over Greenland) was tested and found to stop the runaway cooling (Figure 37).

Figure 36: 16 delta x orography over Baffin Island, Canada.
(Compare with Figures 29 and 30)

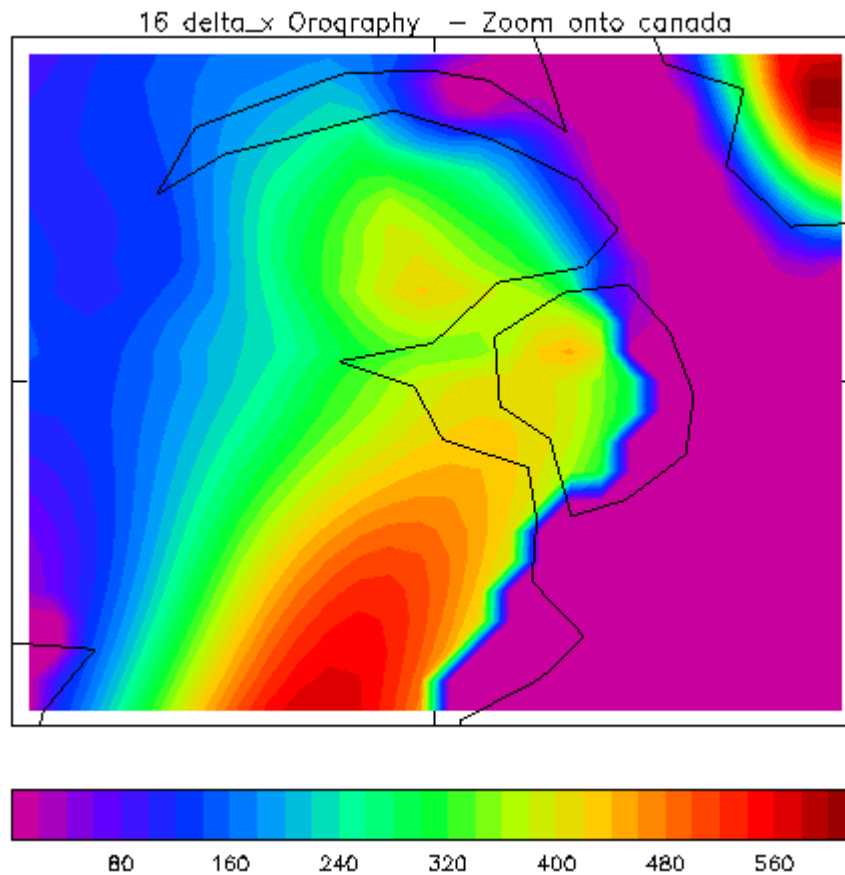
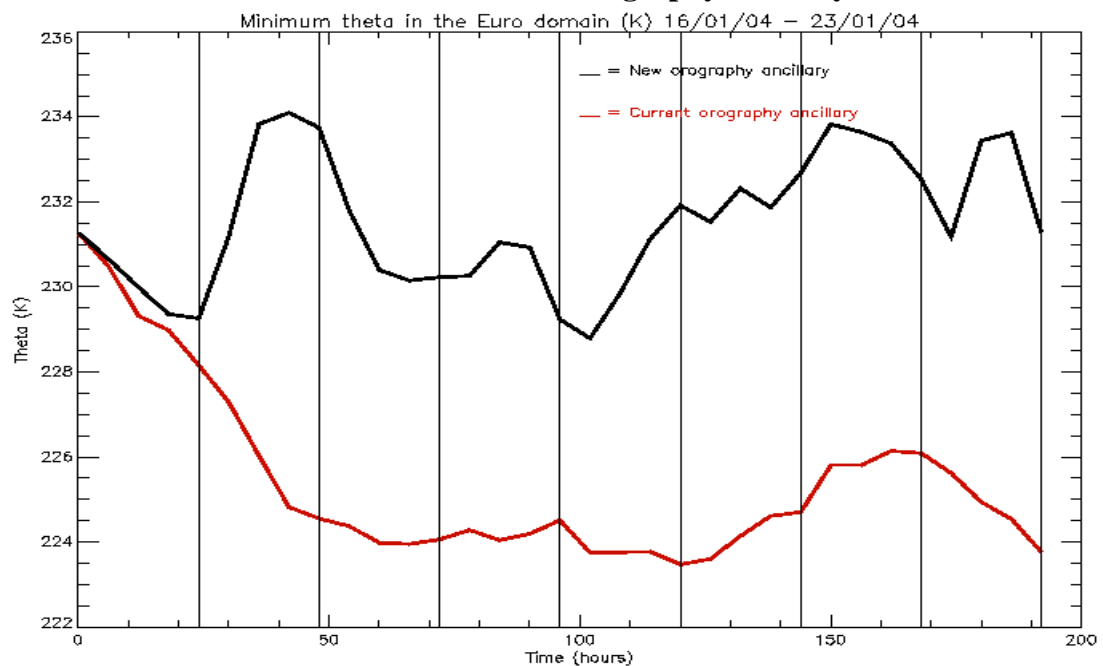


Figure 37: Effect of the new orography ancillary file (black) on the minimum theta in the NAE model domain. Previous orography ancillary file in red.



Meanwhile the investigation into the cause of the problem focused on an inherent instability in the non-interpolating Semi-Lagrangian vertical advection of theta.

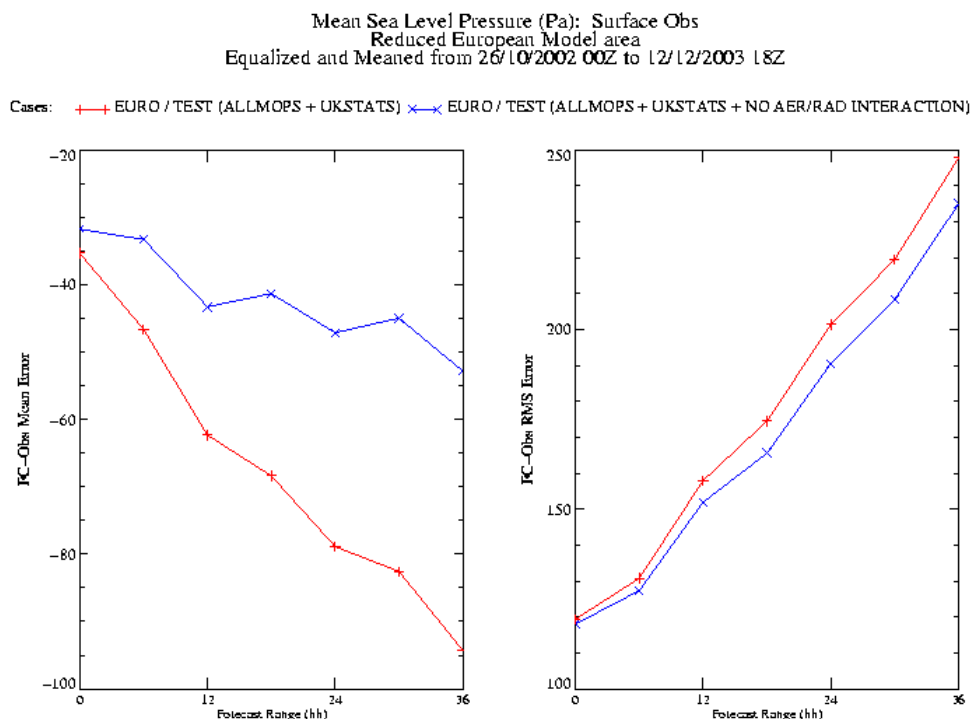
Work continues and it is hoped that if a solution can be implemented, the extra smoothing of the orography can be reversed at some point in the future.

10.3.2 PMSL bias

Since its introduction in late 2001, the NAE has suffered from a noticeable negative PMSL bias. This negative PMSL bias (which grows with forecast time) is linked to a loss of mass. One possible reason for this is that there is insufficient drag being applied within the domain compared to the driving Global model. Tests with a revised surface gravity wave constant of $1\text{E}+05$ (previously $5\text{E}+04$) have shown a reduction in the bias. The chosen value of $1\text{E}+05$ is the same value as in the Global model.

The inclusion of radiative effects of aerosol on visibility (L_MURK_RAD) was found rather unexpectedly to be part of the cause of the PMSL bias. The mechanism appears to be a reduction in the net down SW flux at the surface consistent with the addition of aerosols. This leads to a cooling at the surface over land and a warming above. This warming of the boundary layer then leads to a decrease in density and hence a reduction in PMSL. Tests with L_MURK_RAD set to false show a benefit in terms of reduced PMSL bias (Figure 38) in both the NAE and the UK Mesoscale models (although there is a detriment to temperature forecasts).

Figure 38: Effect of setting L_MURK_RAD to false (blue) on the PMSL bias (left) and RMSE (right). The red is the control and the results are averaged over 15 case studies.



10.4. Performance of the package compared to the Operational NAE model

10.4.1 Objective Performance of the DA package only

The complete DA package was tested in a real time trial with four forecasts per day. The following results are for the period 16th June 2004 to 5th July 2004.

Fig. 39 shows the impact on the five components of the UK index, relative to operational, assessed over the Areas 512 and 503. The impact is uniformly positive, particularly so for screen-level temperature over Area 512. The estimated impact on the UK index for Area 512 is +22%, and +5.9% for Area 503. RMS errors for temperature over Area 512 are also significantly reduced.

Fig 39: Impact of DA upgrade package on weighted ETS /skill for UK index components, versus Control for Verification Areas 512 and 503.

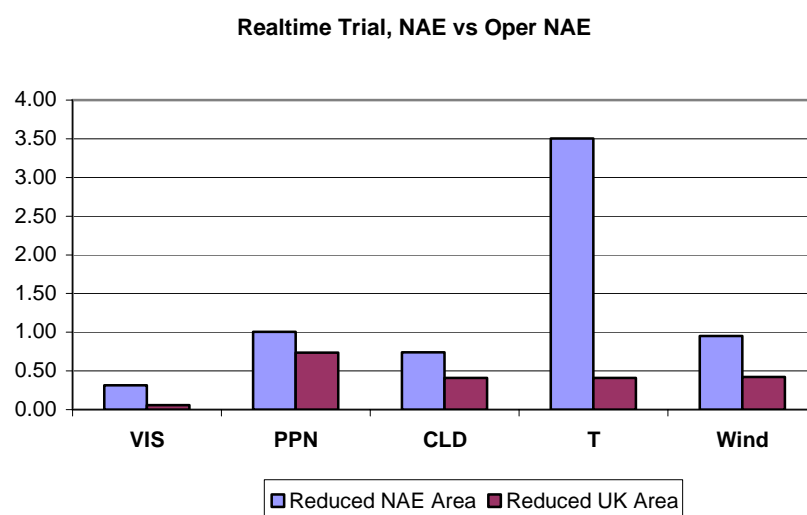
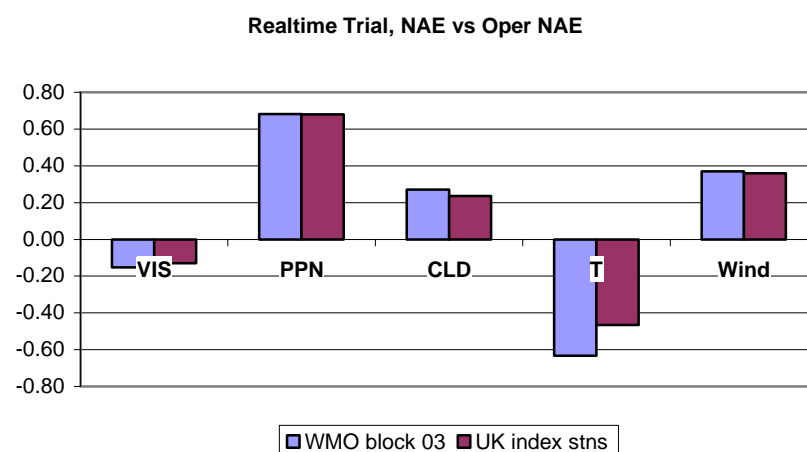


Fig. 40 shows impacts for more restricted sets of stations. WMO block 03 is UK stations only. UK index stations are an even more restricted set of 40 or so stations used operationally to calculate the UK NWP index.

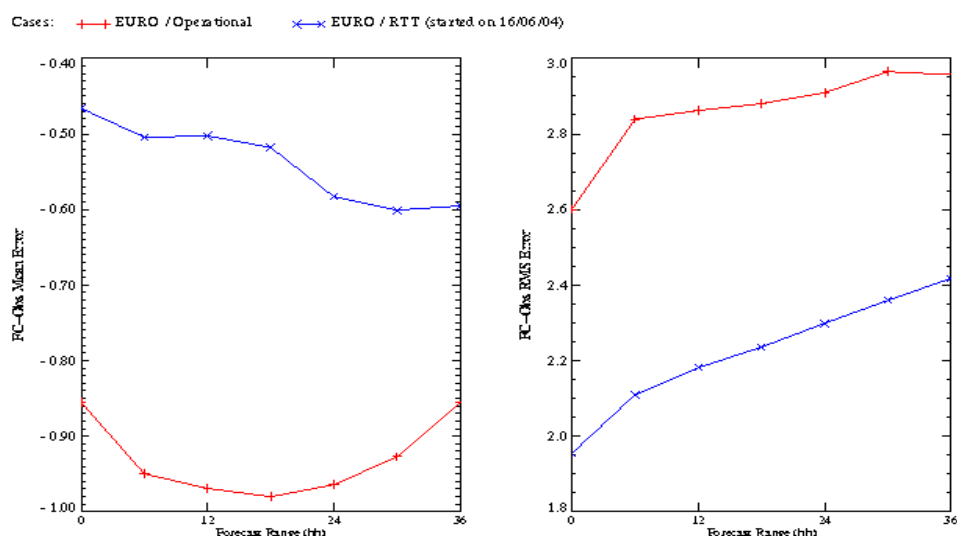
Fig. 40 Impact of DA upgrade package on UK index components, versus Control. WMO block 03 and UK index stations.



The estimated impact for WMO block 03 is +1.5% and for UK index stations +1.8%. In both cases the more mixed signal is caused by the poor temperature skill score. The impact on temperature over the NAE domain would seem to be due to an improved fit to observations in the analysis.

Fig. 41 shows the temperature bias and RMSE against forecast range (relative to observations) for Area 512. The bias at T+0 is considerably better for the trial (blue line) than for the operational (red line).

Fig. 41 Verification of screen-level temperature against forecast hour, over Area 512. Bias (left hand plot) and RMSE (right hand plot). Package in blue and Operational in red.



For the UK Mes area (Fig. 42), bias is initially slightly worse and becomes more so. RMS however is better for the trial over this area as a whole at all forecast times.

Fig. 42 Verification of screen-level temperature against forecast hour, UK mes area, mean (a) and rms (b), trial vs operational

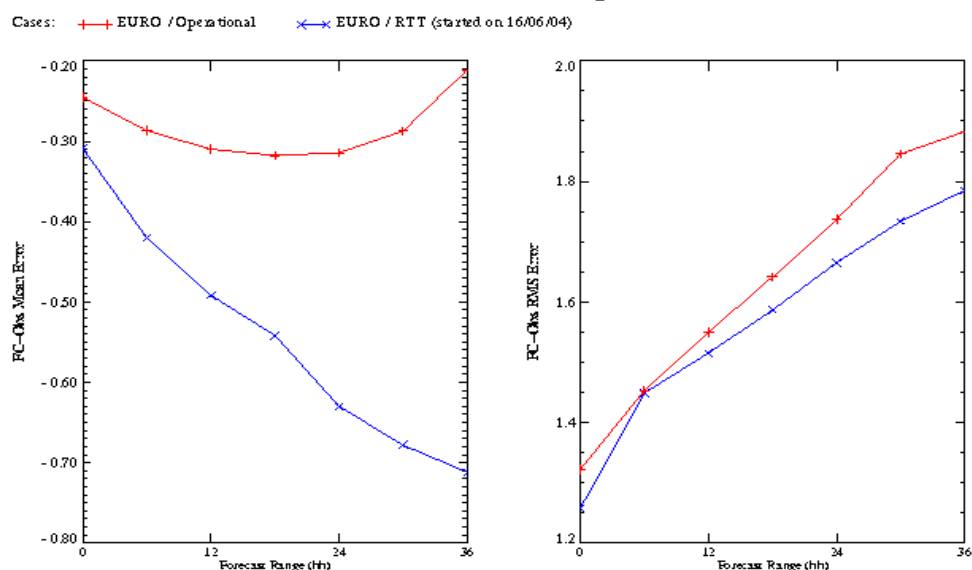
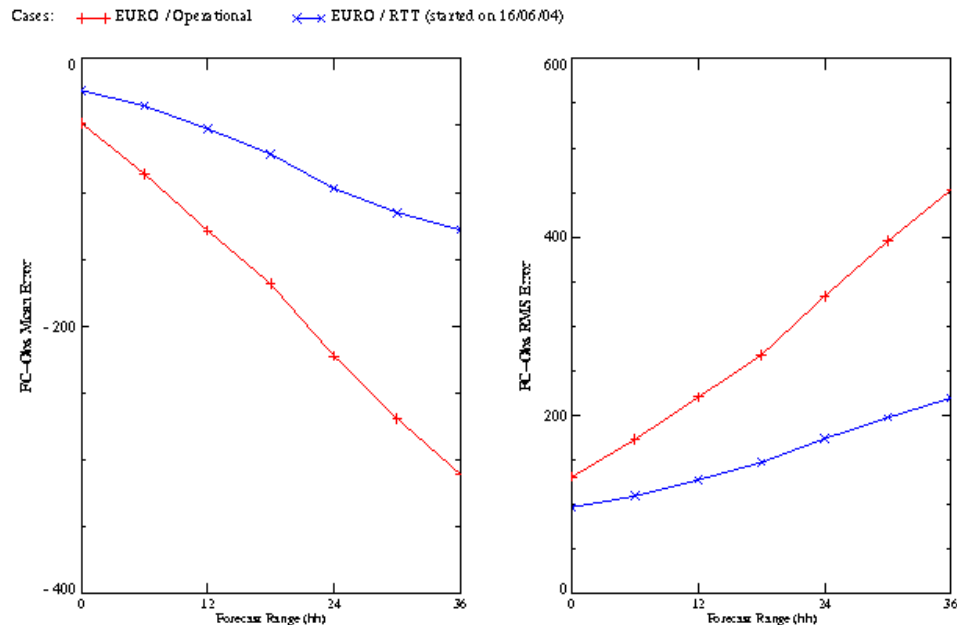


Fig. 43 shows that, as in the case studies, the package has a positive impact on the NAE problem of increasing negative bias in mean sea-level pressure through the forecast. The improvement in both bias and rms is very large and this owes much to a period in the last week in June when the weather was unusually cyclonic and the operational NAE performance unusually poor.

Fig. 43 Verification of mean sea-level pressure against forecast hour, NAE area, mean (a) and rms (b), trial in blue and operational in red.



10.4.2 Subjective Performance of the DA package only

Differences were visible in the operational and trial forecasts for a vigorous system on 7th July 2004. The operational NAE (Figure 44) had a low pressure centre of 988mb over North-West France that was about 6mb deeper than the trial (Figure 45). The verifying U.K Mesoscale model analysis had the low pressure as 994hPa.

Fig. 44 Operational T+12 forecast valid at 00Z on 8/7/04.

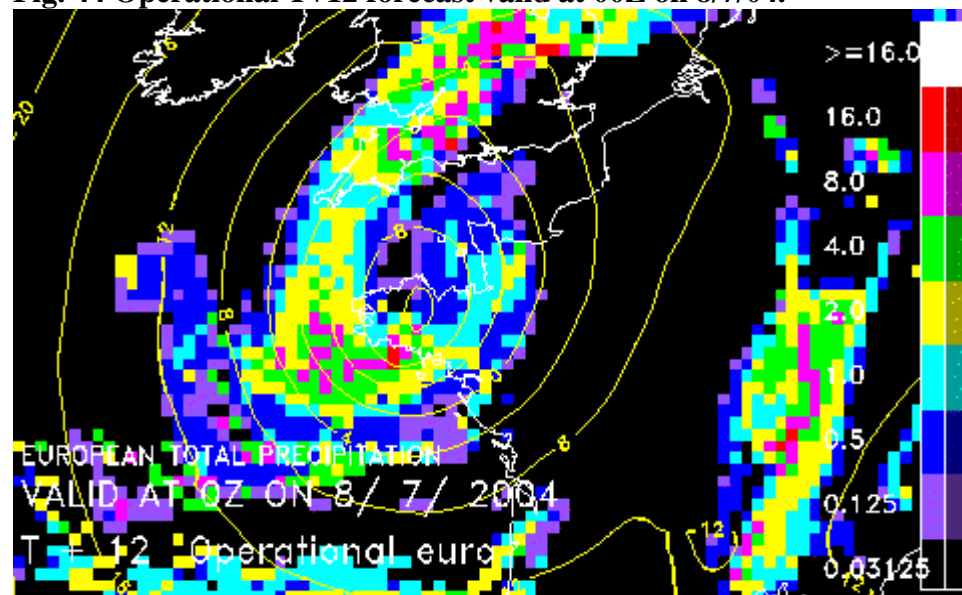
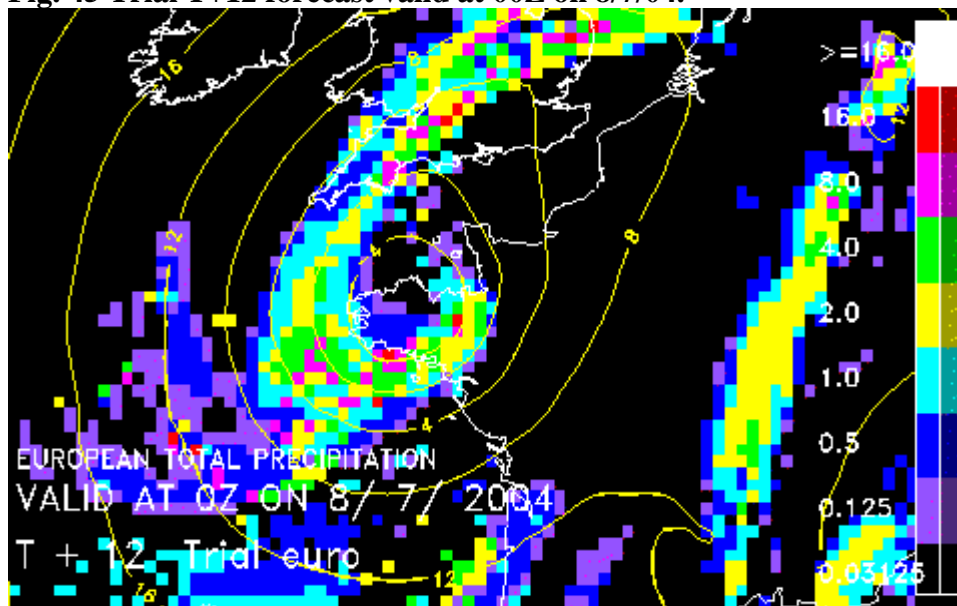


Fig. 45 Trial T+12 forecast valid at 00Z on 8/7/04.



The operational NAE also produced large areas of spurious, intense precipitation in the analysis which declined in the early hours of the forecast. This is evident in Figure 46 over the West Atlantic on 7th July 2004. The trial analysis (Figure 47) is free of this problem although it is unclear as to which part of the DA package was responsible for the improvement.

Fig. 46 Operational NAE analysis

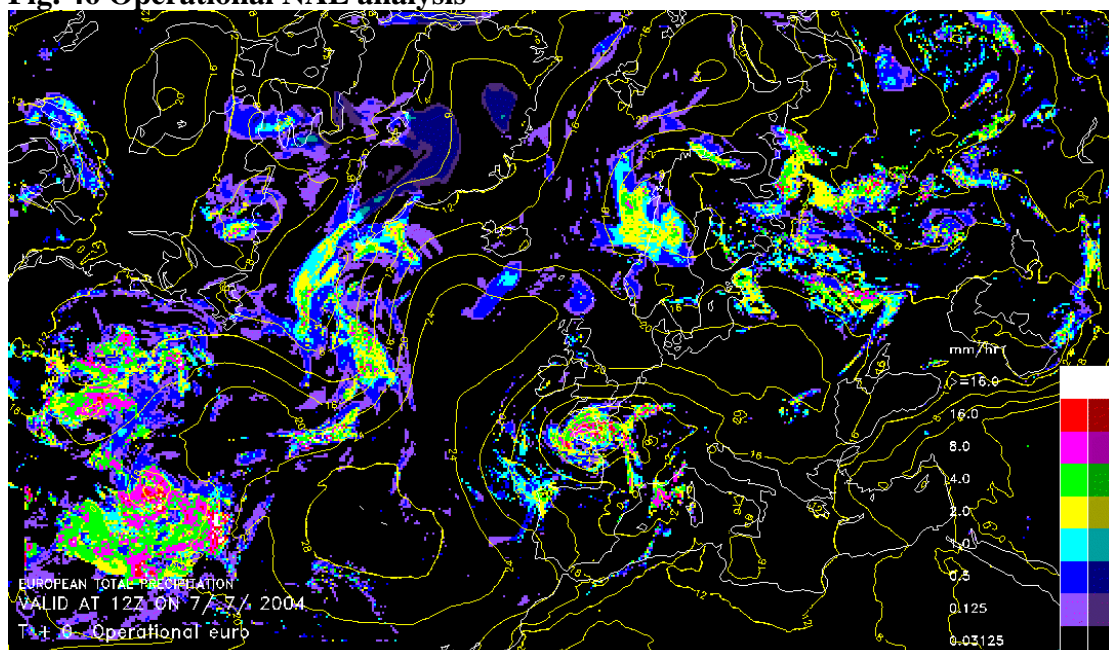
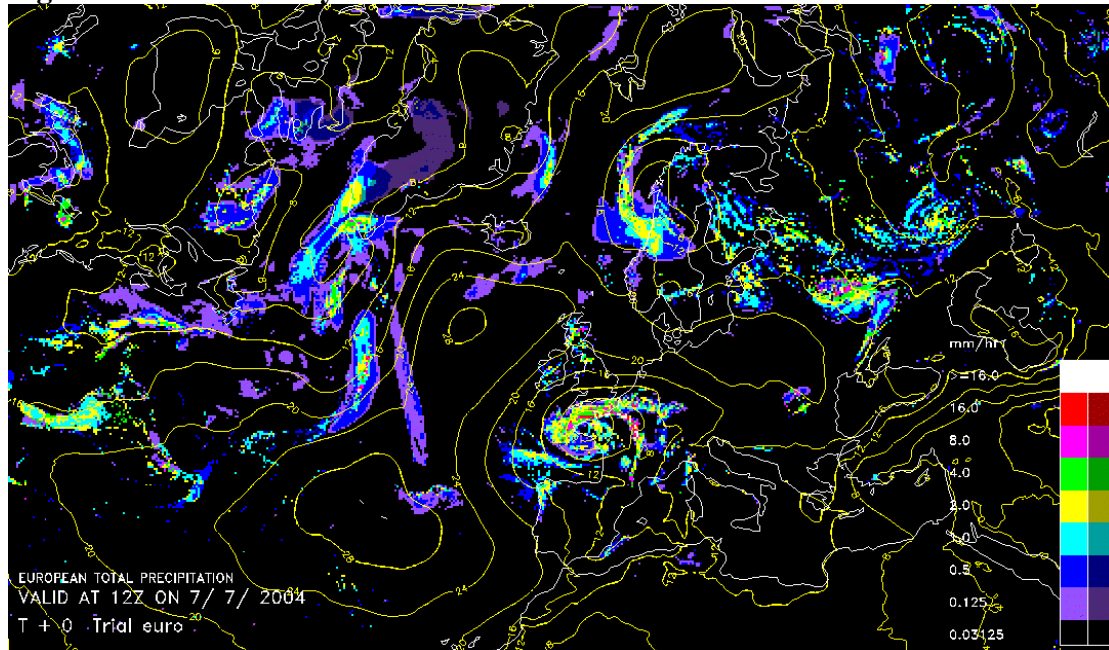


Fig. 47 Trial NAE analysis



10.4.3 Objective Performance of the combined DA/UM package

The complete DA/UM package was run in the parallel suite from 09th August 2004 to 22nd September 2004 and verification results are shown for the period 18th August 2004 to 17th September 2004.

Figure 48: Timeseries of PMSL bias (upper plot) and RMSE (lower plot) at T+24 for the Operational NAE (red) and Parallel Suite NAE (blue) for Area 503.

Cases: —+— Operational —x— Parallel

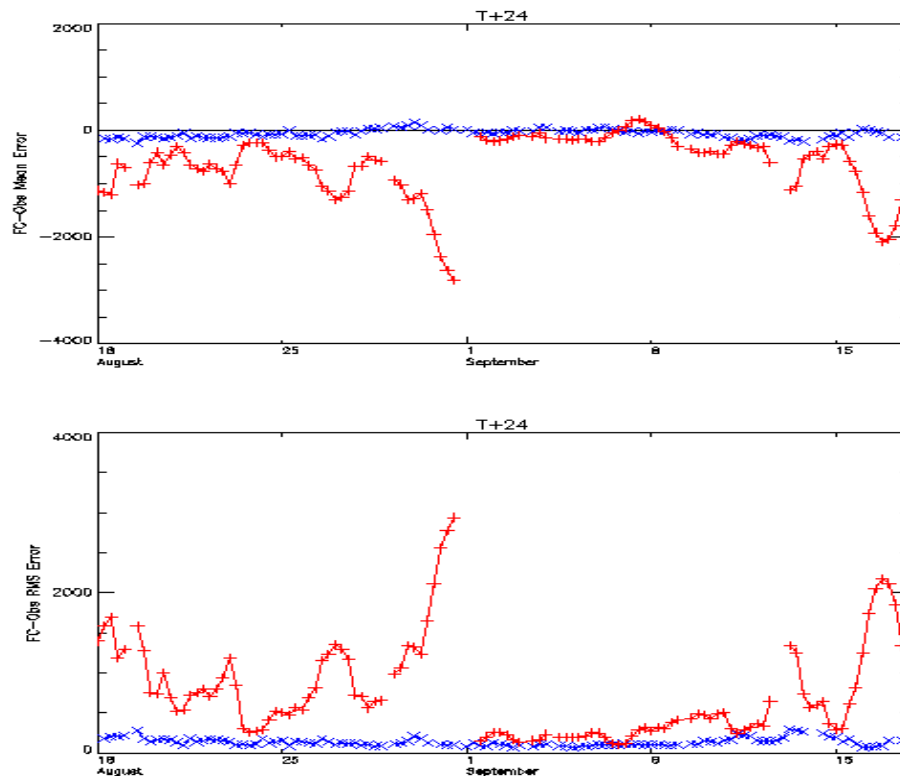


Figure 48 shows NAE parallel suite PMSL compared to the Operational. The Upgrade clearly performs much better than the Operational with a consistently smaller bias and RMSE. The Operational performance dramatically improved in the first few days after 31st August following a reconfigure from Global. However the Upgrade was still superior to the Operational in this period.

10.5. Objective Performance of the package compared to the Global and UK Mes models

The performance of the Upgrade is generally intermediate between Global and UK Mes models for surface variables while upper air performance is still generally worse than either the Global or the UK Mes models. Much of the upper air verification is affected by the overall negative bias in the surface pressure.

10.5.1. PMSL

Figure 49 PMSL verification. Bias (left hand plot) and RMSE (right hand plot). NAE (red), U.K Mes (blue) and Global (green).

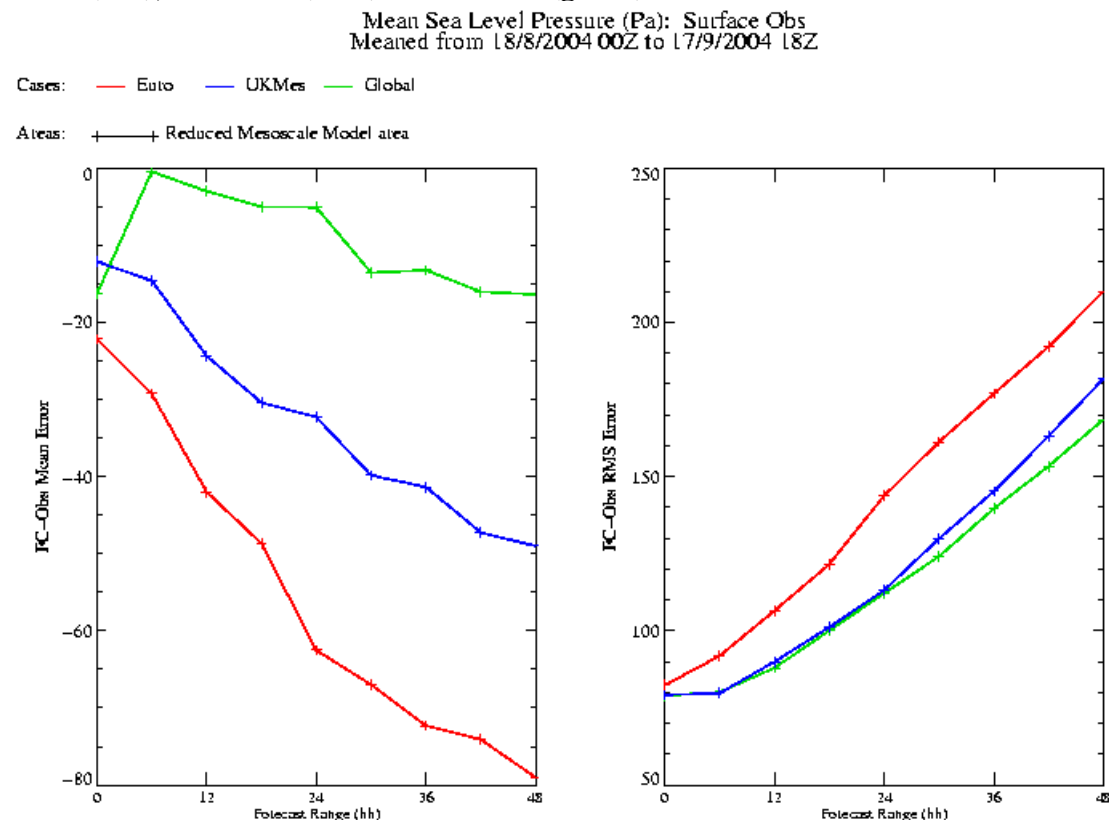


Figure 49 shows PMSL verification. The NAE still performs worse than the Global or UK Mes. Work is in progress to improve the NAE performance, in particular the way in which the Lateral Boundary Conditions are supplied.

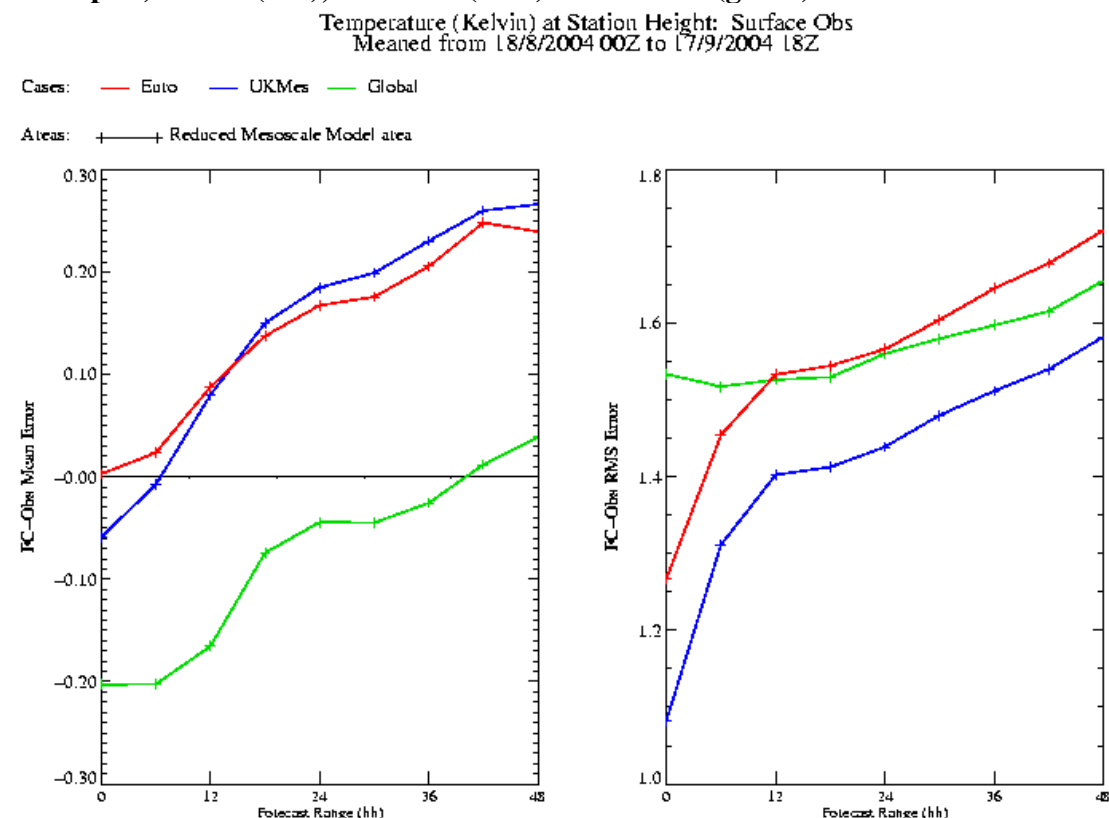
10.5.2. 1.5m Temperature

Figure 50 shows 1.5m temperature verification. The NAE performs better than the Global out to T+12, but is worse at longer forecast ranges and worse than the UK Mes at all forecast ranges.

Work is in progress to assess the impact of verification against corrected/uncorrected obs. The Global and UK Mes models are currently verified against their own set of 'corrected observations' (to correct for station height). Meanwhile the NAE is verified against Global corrected temperatures as NAE corrected temperatures are not yet available.

Also, the UK Mes uses nine surface tiles whilst the NAE only has one tile and the soil moisture update is carried out using MORECS data in the UK Mes and climatology in the NAE.

Figure 50: 1.5m Temperature verification. Bias (left hand plot) and RMSE (right hand plot). NAE (red), U.K Mes (blue) and Global (green).



10.5.3. Cloud

Figure 51 shows Cloud cover verification over the reduced Mesoscale model area. The NAE performs better than the Global model at all forecast ranges and has a smaller bias. RMS errors are still slightly higher than for the UK Mes.

10.5.4. 10m Wind

Figure 52 shows wind verification over the reduced Mesoscale model area. The NAE wind speed bias is lower than the Global model out to T+18, but is worse at longer forecast ranges. The RMS errors are generally better than the Global throughout the forecast range.

Figure 51: Fractional Cloud Cover verification. Bias (left hand plot) and RMSE (right hand plot). NAE (red), U.K Mes (blue) and Global (green).

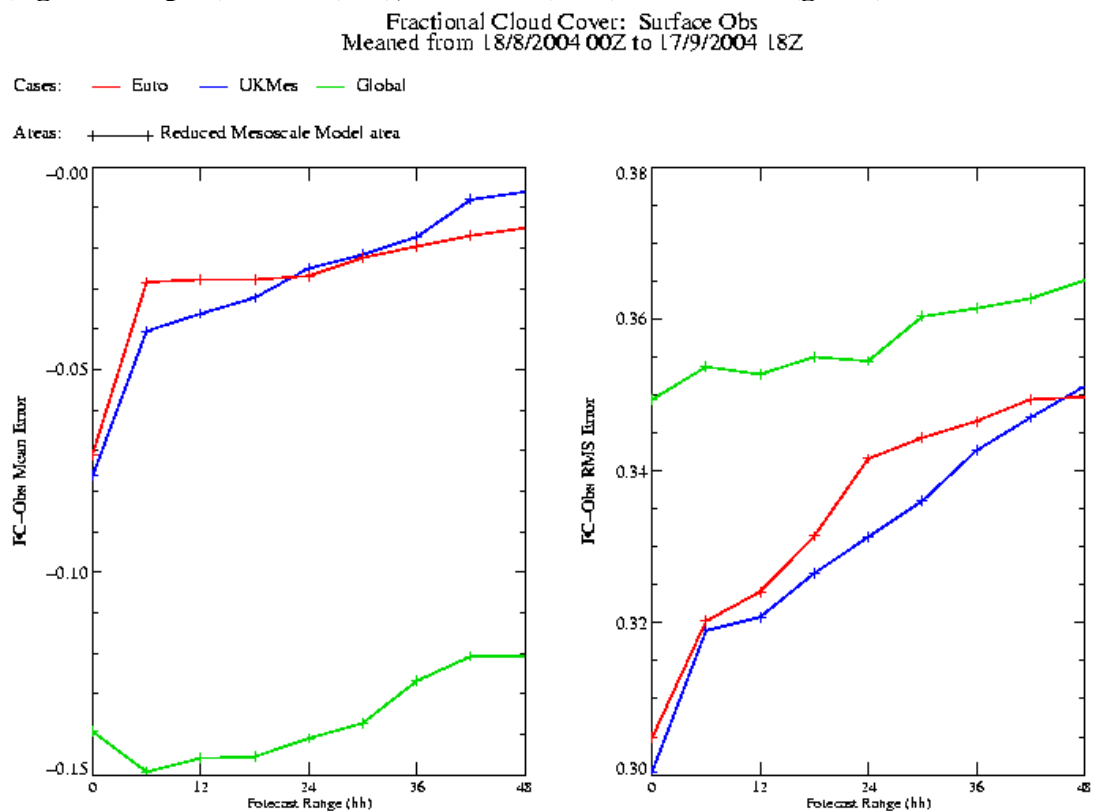
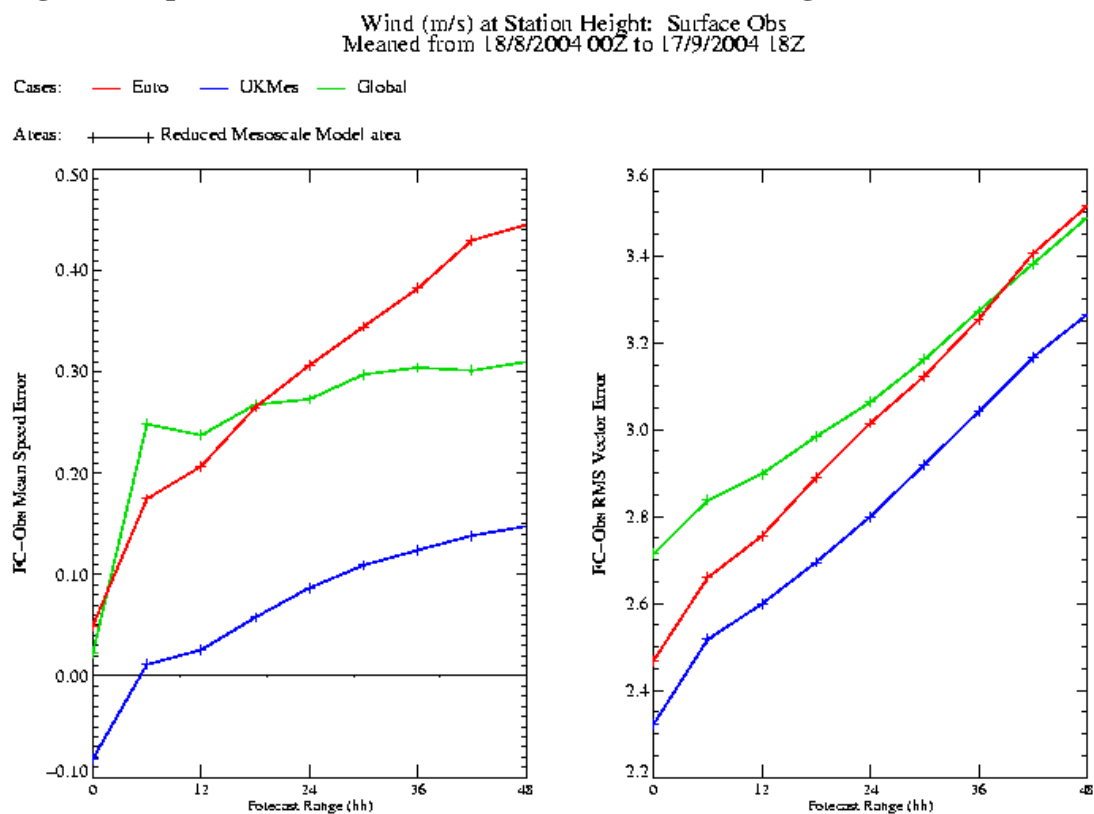


Figure 52: Wind speed verification. Bias (left hand plot) and RMS Vector Error (right hand plot). NAE (red), U.K Mes (blue) and Global (green).



10.5.5. Visibility

Figure 53 shows visibility verification over the reduced Mesoscale model area. The plots are quite noisy due to the relatively small sample size, however the NAE generally performs better than either the Global or UK Mes models, especially up to T+24 forecast range.

10.5.6. Precipitation

Figure 54 shows precipitation verification over the reduced Mesoscale model area. The plots are once again quite noisy due to the relatively small sample size, however the NAE generally performs better than the Global at the 0.2mm and 1.0mm thresholds and worse than the UK Mes model at all forecast ranges.

10.5.7. 850mb RH

Figure 55 shows 850mb RH verification over the reduced Mesoscale model area. The NAE performs worse than the Global or UK Mes models.

10.5.8. 500mb Height

Figure 56 shows 500mb Height verification over the reduced Mesoscale model area. The NAE performs worse than the Global or UK Mes models.

10.5.9. 250mb wind

Figure 57 shows 250mb wind verification over the reduced Mesoscale model area. The NAE performs worse than the Global or UK Mes models.

Figure 53: Visibility verification. ETS scores for 200m (left hand plot), 1000m (middle plot) and 5000m (right hand plot). NAE (red), U.K Mes (blue) and Global (green).

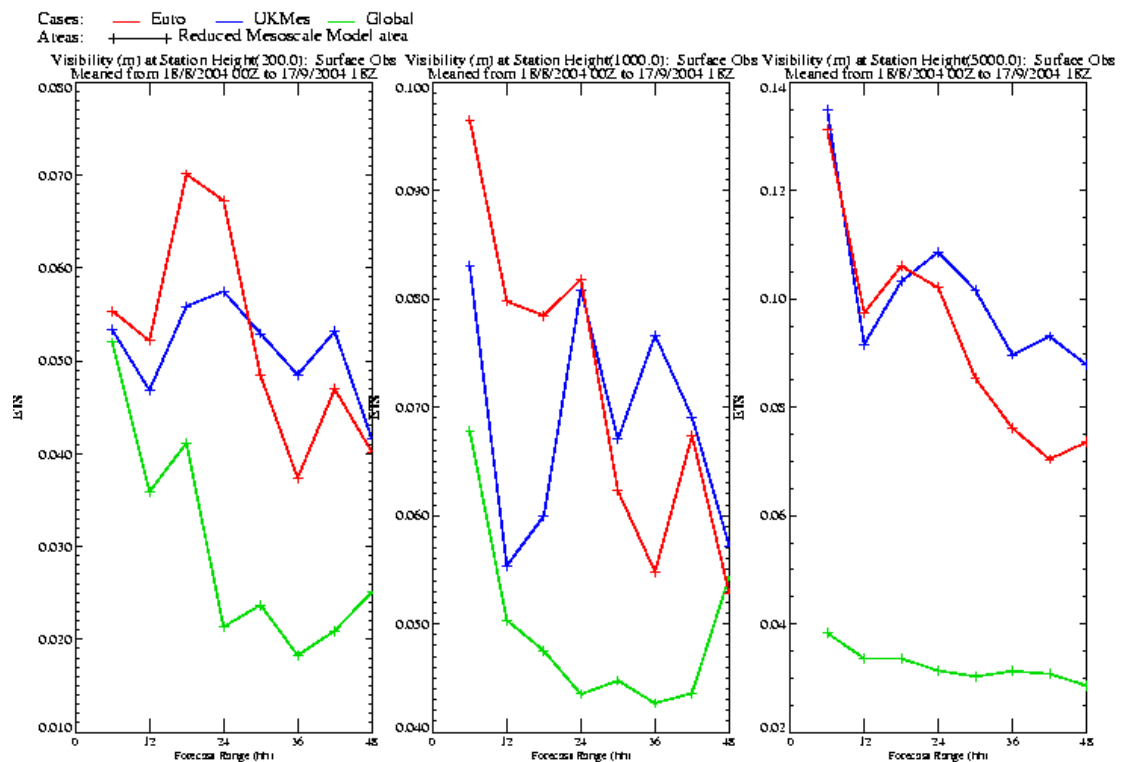


Figure 54: 6 hr Precipitation Accumulation. ETS scores for 0.2mm (left), 1mm (middle) and 4.0mm (right plot). NAE (red), U.K Mes (blue) and Global (green)

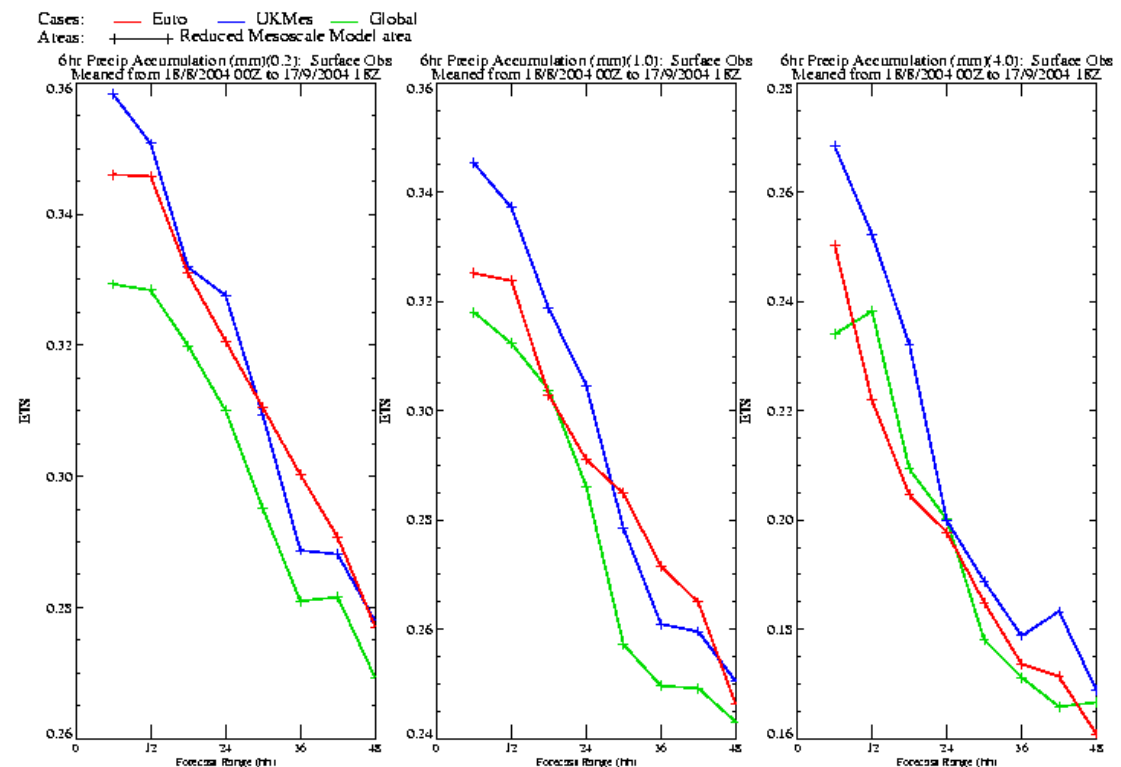


Figure 55: 850mb RH verification. Bias (left hand plot) and RMSE (right hand plot). NAE (red), U.K Mes (blue) and Global (green).

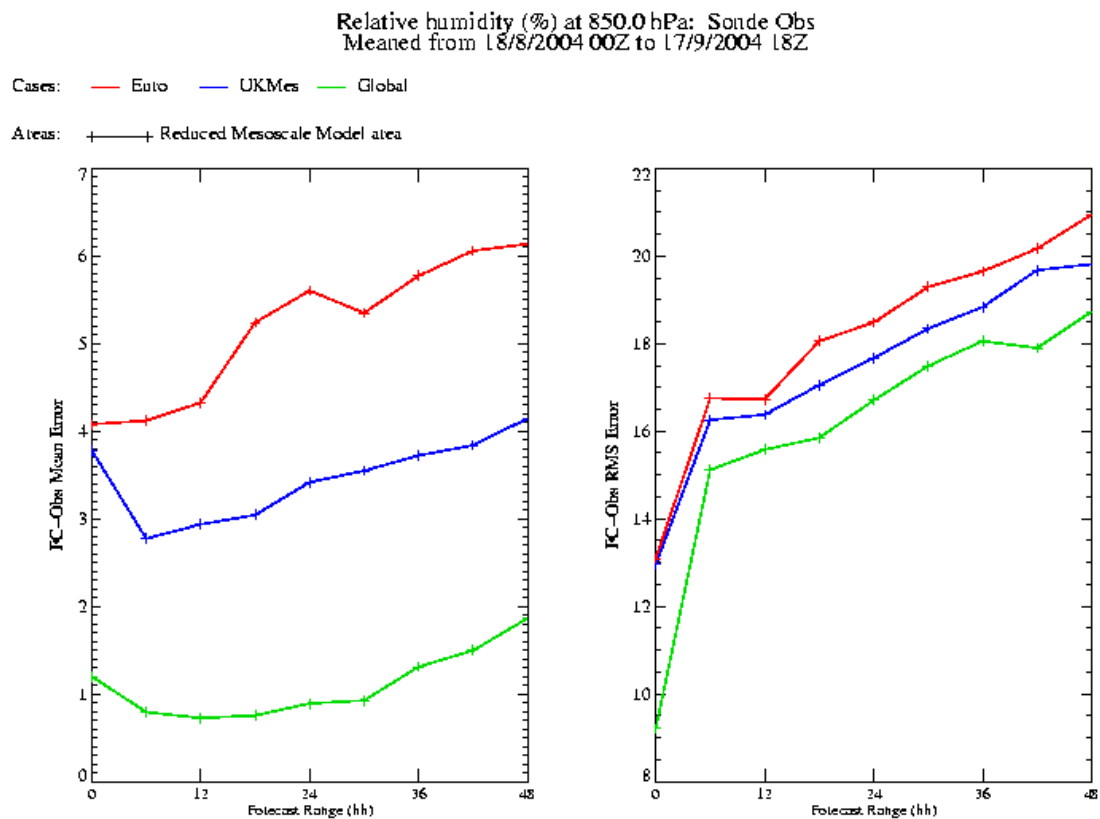


Figure 56: 500mb Height verification. Bias (left hand plot) and RMSE (right hand plot). NAE (red), U.K Mes (blue) and Global (green)

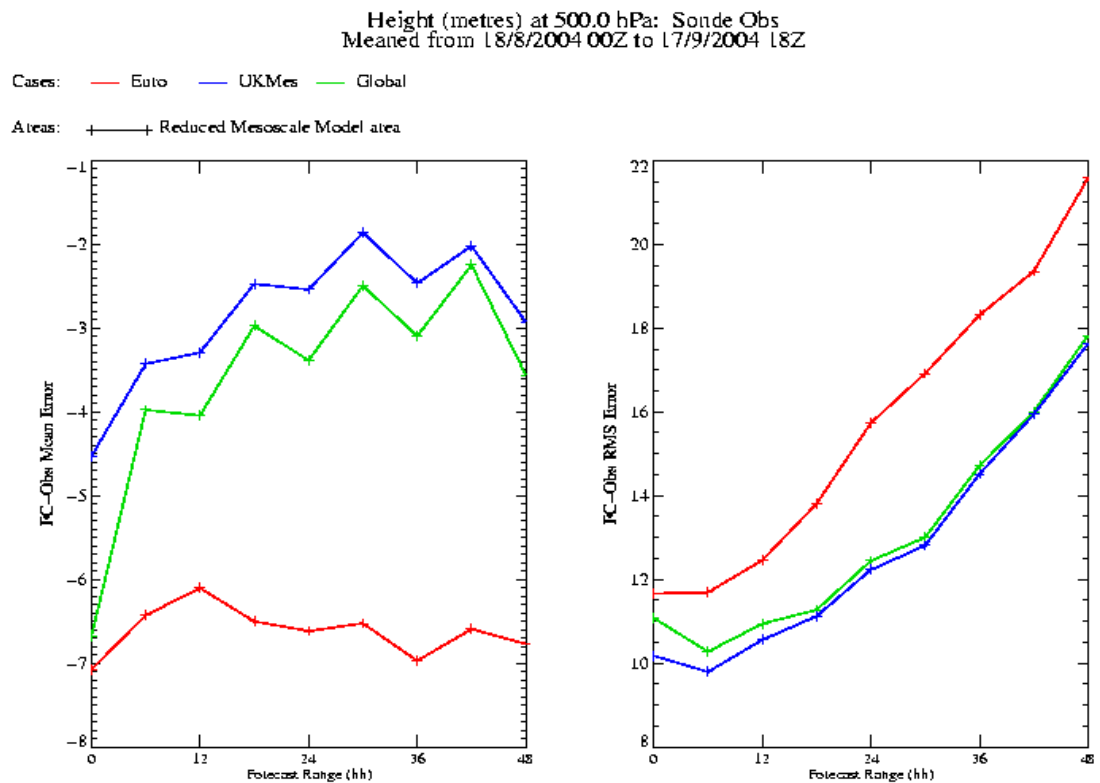
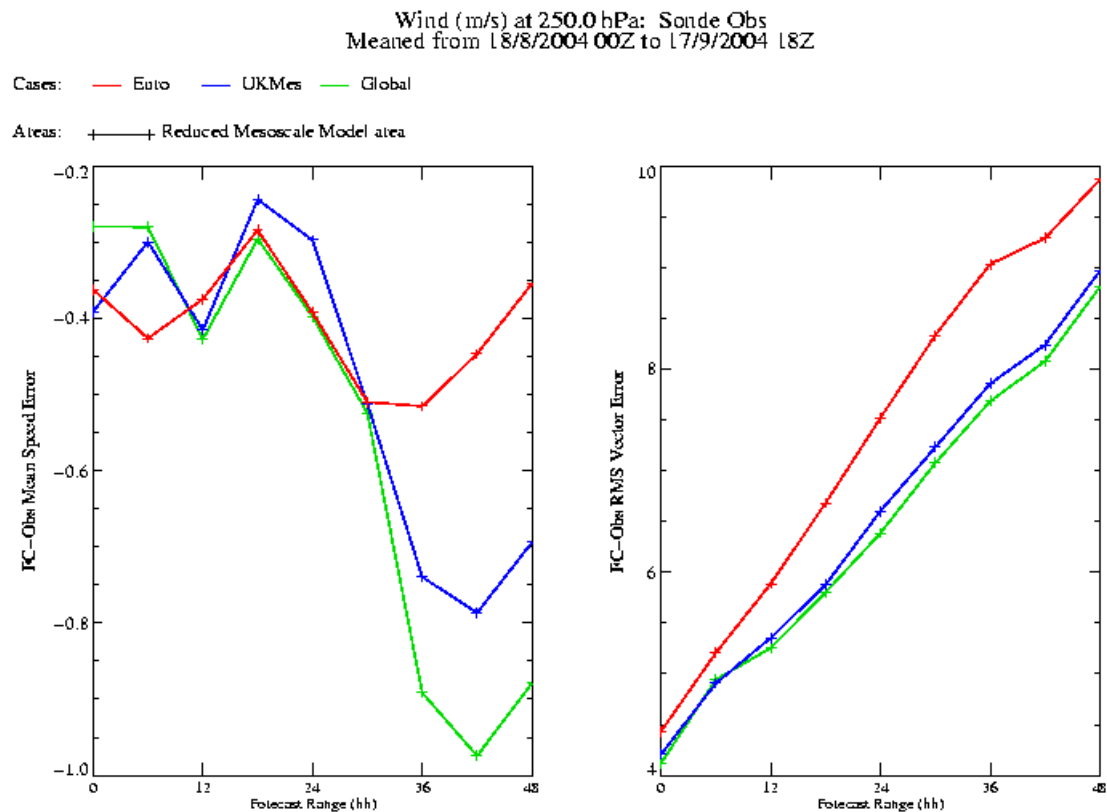


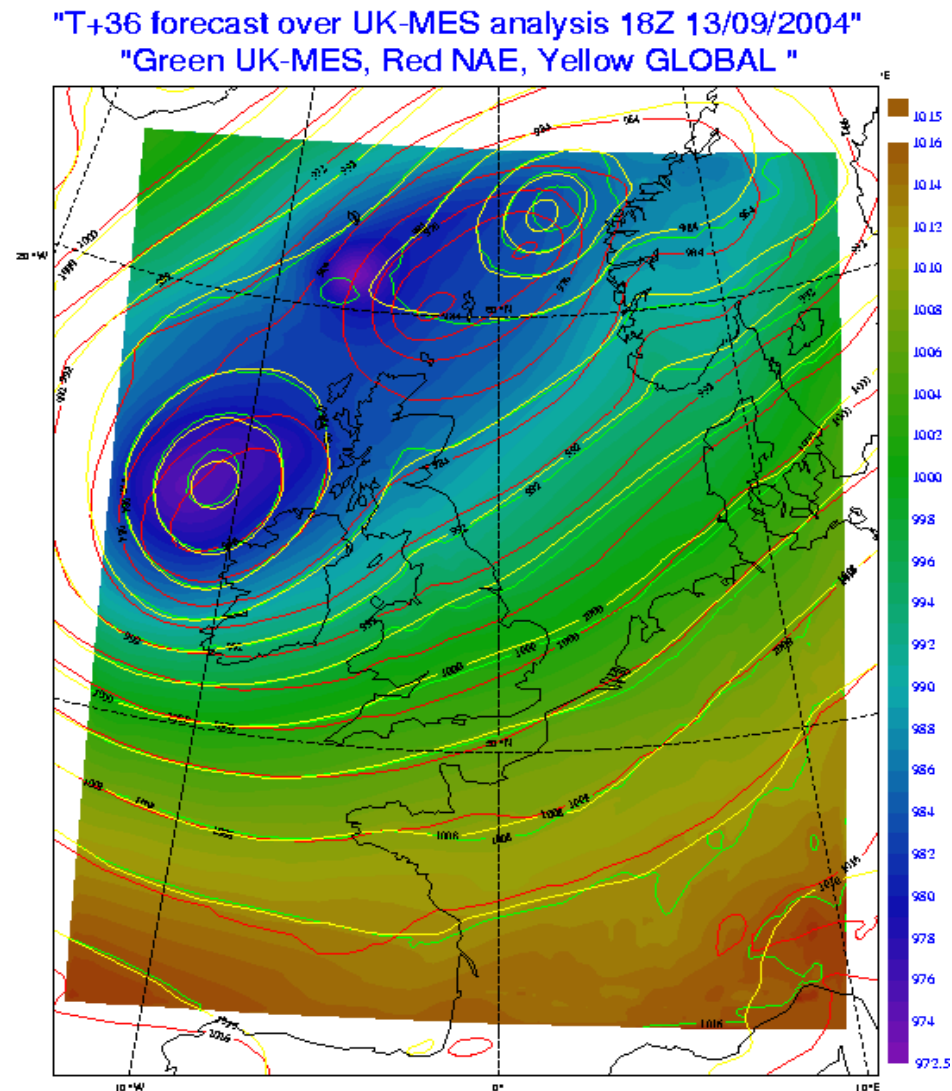
Figure 57: 250mb wind verification. Bias (left hand plot) and RMS Vector Error (right hand plot).



10.6 Subjective Performance of the of the package compared to the Global and UK Mes models

On 13th September 2004 a significant difference was noted between the NAE trial forecast and the Global and U.K Mes model forecasts. Figure 58 shows PMSL contours for T+36 forecasts from the NAE (red), Global (yellow) and U.K Mes (green) overlayed on a coloured U.K Mes analysis. It shows the low centre to be further west than predicted by any of the models. However the trial NAE produces a better forecast than either the Global or U.K Mes models. The U.K Mes model solution is tightly bound to the Global solution via the lateral boundary conditions due to its small domain size.

Figure 58: PMSL contours for T+36 forecasts from the Trial NAE (red), Global (yellow) and U.K Mes (green) overlaid on a coloured U.K Mes analysis.



11) UM upgrade package (18/01/2005)

The UM upgrade for the North Atlantic and European (NAE) model has been tested in Parallel Suite 3.0 and is designed to improve the model performance and prepare for the introduction of a 12km version in February 2005.

The main changes are:

- 1) Reducing the model domain from 548x320 gridpoints to 450x250 gridpoints, thus reducing computer costs.
- 2) Changing the rotated pole coordinates to make the NAE the same as the U.K Mes, for ease of replacement of U.K Mes products.
- 3) The alpha_1 and alpha_3 weights in the primary field advection are changed from 0.6 to 0.7 to stop numerical instabilities.
- 4) An updated UM executable.
- 5) The use of new ancillaries including a 38 level ozone ancillary (previously 11).

Domain change

The change to the domain is in preparation for the 12km resolution change in February 2005 and the transfer of products from the U.K Mes to the NAE. The domain seen by customers was reduced in the previous upgrade (22/09/04) but the model domain was left untouched. This change brings the model domain into line.

Alpha change

Figure 59 shows the effect of the new alpha_1 and alpha_3 coefficients. The numerical noise seen in the Operational run is stability dependent and only develops when there is strong flow. This noise has been eliminated in the Parallel Suite run.

Model Executable change

- Inclusion of a modset to revise the diagnosis of cumulus boundary layers, diagnosing shear-driven ones instead when the buoyancy is close to neutral. This is beneficial in avoiding some erroneous low wind forecasts over the North Sea.
- Removal of a convection modset that took the 4A scheme back towards the UM5.3 Global CMODS version
- Inclusion of a modset to prevent the occasional occurrence of a run-time error after the model has finished.

Ozone change

The change in vertical levels associated with the New Dynamics (implemented in August 2002) introduced an inconsistency in the treatment of ozone in limited area versions of the UM. This was due to there being 11 levels of ozone instead of 38 (a memory saving feature).

The use of a 38 level ozone ancillary has a number of effects. The negative PMSL bias is reduced and 1.5m temperatures are cooled. This reduces the temperature bias slightly in Winter but does not lead to a reduction in RMSE. The amount of light precipitation (0.2mm threshold) is reduced and this verifies slightly worse. However, the reduction of light precipitation over the sea looks better subjectively. There is some evidence that heavy precipitation (>4.0mm threshold) verifies slightly better. Overall the 6 hour precipitation accumulation verifies slightly worse for UK Index stations and a little worse for Block 03 stations (Figures 60 and 61).

Verification

Figures 60 and 61 summarise performance of the Parallel Suite 3.0 NAE versus the then current Operational NAE.

1.5m temperature results

The degradation to 1.5m U.K Index scores is most severe for Area 2011 (-0.275) and Area 513 (-0.214). The results for Area 2103 were slightly negative (-0.073) and the results for Area 503 slightly positive (0.011).

Figure 59: Effect of the new alpha_1 and alpha_3 coefficients on numerical instabilities at T+33. VT 9z 05/01/2005. Operational NAE (top) and Parallel Suite 3.0 NAE (bottom).

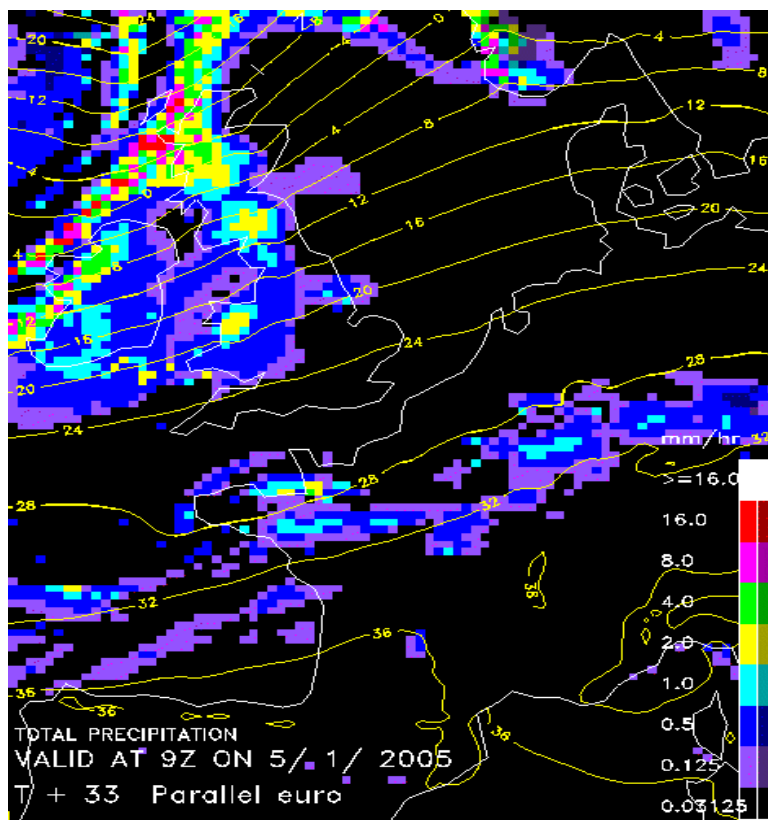
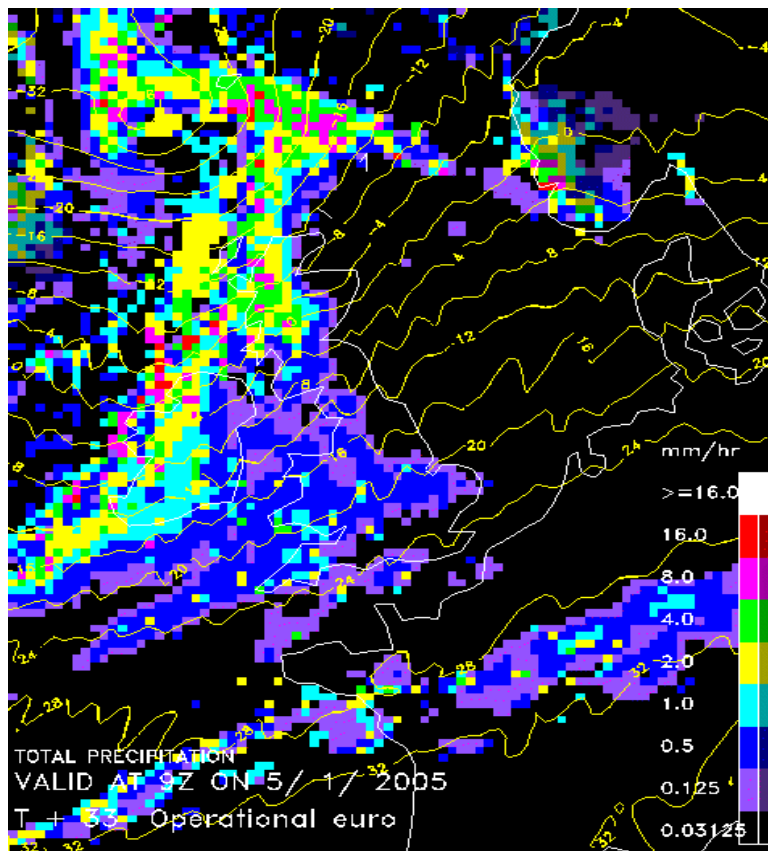


Figure 60: 30 days of verification over Area 2011 (U.K Index stations)

Parameter	Control Data	Test Data	Test - Control
	Mean ETS	Mean ETS	Wted ETS Diff
Surface Visibility	0.131	0.139	0.164
6 hr Precip Accum	0.363	0.358	-0.089
Total Cloud Amount	0.299	0.297	-0.035
	Mean Skill	Mean Skill	Wted Skill Diff
Surface Temp	0.836	0.822	-0.275
Surface Wind	0.742	0.747	0.099

Total Weighted Score (%)

Control Case = 47.393

Test Case = 47.256

Test - Control = -0.137 (-0.29 % change)

Figure 61: 30 days of verification over Area 2103 (Block 03 stations)

Parameter	Control Data	Test Data	Test - Control
	Mean ETS	Mean ETS	Wted ETS Diff
Surface Visibility	0.106	0.114	0.151
6 hr Precip Accum	0.355	0.345	-0.216
Total Cloud Amount	0.281	0.284	0.056
	Mean Skill	Mean Skill	Wted Skill Diff
Surface Temp	0.826	0.822	-0.073
Surface Wind	0.745	0.746	0.032

Total Weighted Score (%)

Control Case = 46.260

Test Case = 46.210

Test - Control = -0.051 (-0.11 % change)

Area 2011 (U.K Index stations) results are the most sensitive to small amounts of verification data due to the limited number of stations used. It is encouraging therefore to see the results improving with increased numbers of stations as one goes to Area 2103 and then Area 503.

The 1.5m temperature bias and RMSE as a function of forecast range are presented in Figure 62. It can be seen that the Parallel Suite 3.0 package (yellow) reduces the positive bias compared to the Operational (red). The RMSE is only increased slightly.

Figure 63 shows the geographical differences in 1.5m temperature between the Parallel Suite 3.0 and Operational NAE models at 12z on 02/01/2005. It can be seen that the major differences lie outside of the U.K area. Blue indicates that the Parallel Suite 3.0 NAE is colder than the Operational NAE.

Figure 62: 1.5m temperature verification over the reduced Mesoscale Area.
a) Bias (left hand plot) and b) RMSE (right hand plot).

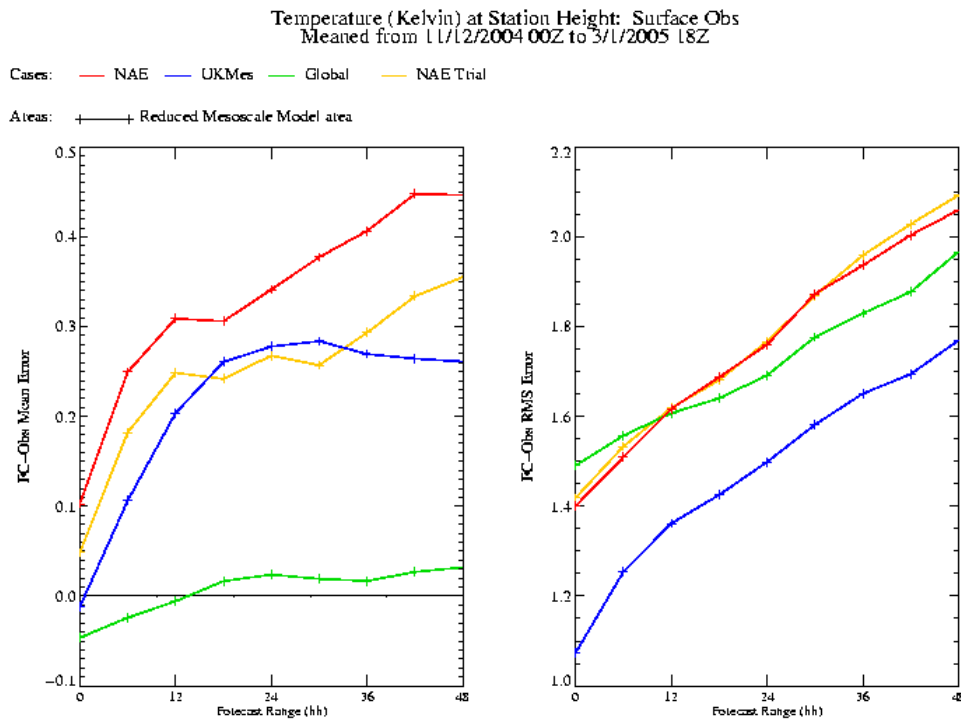
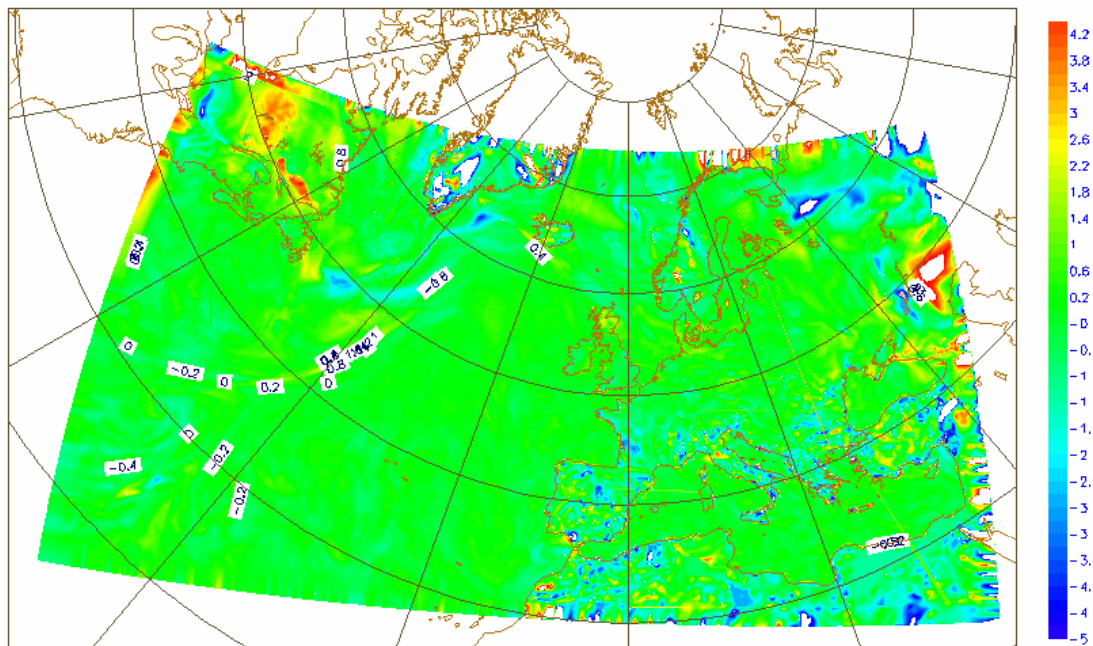


Figure 63: 1.5m temperature differences between the Parallel Suite 3.0 and Operational NAE models at 12 z on 02/01/2005.

Sunday 2 January 2005 12UTC BRAKL Forecast t+12 VT: Monday 3 January 2005 00UTC 9999m TEMPERATURE AT 1.5M



The overall change in index is close to neutral, with improved visibility, winds and cloud (for Block 03) compensating deteriorations in surface temperature and precipitation. Despite these negative impacts, the improved stability (Figure 59), reduced domain (and cost), and corrected ozone were all desirable. Therefore this package was implemented operationally on 18th January 2005.

Concluding remarks

This note documents the various development stages of the regional NAE model. The project was more difficult than envisaged originally with several problems occurring such as valley cooling, increased noise and grid point storms. Also more effort (which is continuing) is needed to optimise the data assimilation. The smaller domain U.K Mesoscale model is more closely coupled to the behaviour of the Global model and it is proving a challenge to match its performance.