METEOROLOGICAL OFFICE

Forecasting Research

Forecasting Research Division
Technical Report No. 160

The Spring 1995 Mesoscale Model Upgrade

by

P.A. Clark, S.D. Jackson, A. Maycock, B. Macpherson, R.N.B. Smith and S.A. Woltering

May 1995

Meteorological Office
London Road
Bracknell
Berkshire
RG12 2SZ
United Kingdom

Forecasting Research Division Technical Report No. 160

The Spring 1995 Mesoscale Model Upgrade

P.A. Clark, S.D. Jackson, A. Maycock, B. Macpherson, R.N.B. Smith and S.A. Woltering

FR Division, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, UK

(May 1995)

Abstract

In April 1995 a package of changes were made to the operational Mesoscale model. These changes were designed to address a number of known biases in the model and were accepted as a result of the results of a programme of trials, including a number of representative case studies. This Report summarises briefly the changes that were implemented and the result from the trials.

The Spring 1995 Mesoscale Model Upgrade

P.A. Clark, S.D. Jackson, A. Maycock, B. Macpherson, R.N.B. Smith and S.A. Woltering

Forecasting Research Division,

May 1995

1. Abstract

In April 1995 a package of changes were made to the operational Mesoscale model. These changes were designed to address a number of known biases in the model and were accepted as a result of the results of a programme of trials, including a number of representative case studies. This Report summarises briefly the changes that were implemented and the result from the trials.

2. Changes

The changes are summarised as follows:

MODEL FORMULATION

1) Modifications to the orographic roughness scheme to implement the most up-to-date formulations for the surface turbulent transfer coefficient for scalars and for the 10 m wind diagnostic. This brings the formulation in line with the version currently operational in the LAM and global models. The revised 10 m wind diagnostic will have the effect of increasing 10 m winds in many cases.

2) A modification to the diagnosis of screen level temperature and humidity in unstable conditions. The current UM surface layer interpolation formulae in unstable conditions are inconsistent with the free-convective limits implied by the model's surface flux formulation. In addition there is uncertainty as to what the correct free-convective flux formulation should be. Thus there is no reason for any confidence in the currently employed unstable surface layer interpolation coefficients. As an interim measure the interpolation coefficient for the screen level temperature and moisture diagnostics has been set to its neutral value for all unstable surface layer profiles. This has some theoretical justification from a free-convective theory which uses the velocity scale of the large eddies in unstable boundary layers. The modification should go some way towards correcting the model's cold bias in summer daily maximum temperatures.

3) Correction to convective downdraught initiation code to use height above the surface rather than a hard-wired level number. This is included to make the code more general, and the effect is generally negligible.

4) Modification to the treatment of horizontal diffusion. This improved formulation is intended to improve behaviour around orography, where the current treatment results in excessive and unrealistic vertical mixing. The benefits are expected to be greatest in the treatment of fog.

5) Modification of the advection of aerosol for visibility. With version 3.4 in place it is relatively straightforward to modify the code so that only aerosol in the boundary layer is advected. This is intended purely as a cost saving measure. Null impact on the forecast development will result and negligible impact on the visibility diagnosis.

6) Modification to the visibility diagnosis parameters. Since the aerosol variable went operational routine verification statistics have been monitored. These show a general bias, in that visibilities are generally diagnosed too high. The parameters defining 'typical' particle sizes have been re-tuned using these data. The original values were the same as those used in the old mesoscale model, while the revised values are rather more in line with what one might expect from the literature and values being used in the Hadley Centre (although they are not the same, as the Hadley Centre values are intended to be representative of the troposphere as a whole). In addition a small diurnal variation in aerosol source strength has been added to improve the evolution of the visibility forecast.

MOPS

One of the most significant sources of known systematic error in the model is the tendency to initiate spurious mid-level convection. This has been identified as a feature of the MOPS cloud analysis, which can erroneously identify thin cirrus as mid-level cloud. A modification has been developed which prevents MOPS inserting cloud at lower levels if cloud is present in the background field at high levels. In addition, the assimilation code and MOPS code has been modified to pass cloud cover in the MOPS ACobs file, rather than RH, so that changes to the cloud scheme do not require new ACobs files to be created. In the assimilation of MOPS data, model convective cloud cover is now combined with layer cloud fraction (as in the radiation scheme) before comparison with the MOPS observation.

DATA ASSIMILATION

1) Revised assimilation parameters have been derived from the OPD. In particular, new assimilation parameters have been derived for 10 m winds, upper air temperature and wind data.

2) Assimilation of (log) visibility data to correct the initial aerosol fields for visibility analysis. This is very inexpensive and brings the model up to an approach similar to that used in the old mesoscale model.

3) The radar 'blacklist' for the surface hydrology correction scheme has been revised, based on an extended comparison between FRONTIERS monthly accumulations and MORECS data. This will have a minor regional effect on soil moisture.

4) The model soil moisture will be allowed to evolve freely during assimilation and the practice of daily resetting to climatology will be discontinued.

3. Resources

The impact on resources is negligible. The change to the diffusion scheme adds to the CPU usage, typically increasing it by between 3 and 5%, while the reduction in advected aerosol levels saves typically about 8% of CPU. There is therefore a net saving in CPU of a few %. In addition there is a small increase in the ACobs file size to accommodate visibility data, amounting typically to about 15-20 kB, or 11-15% of the file size.

4. Testing procedure

Several individual proposed changes were tested separately using a number of cases which were representative of the problems being addressed. The components of the package were selected from these changes on the basis of these initial trials. The full package was then run using 10 cases selected to be representative of a wide range of meteorological conditions, including some in which little impact is envisaged.

1) 14 October 94, 00Z Run, Radiation fog.

2) 23 November 1994, 06Z Run, Spurious middle level instability.

3) 17 January 1995, 06Z Run, Frontal rain.

4) 5 August 1994, 06Z Run, Clear summer day.

5) 8 October 1994, 06Z Run, Radiation fog associated with an old stationary front..

6) 6 October 1994, 00Z Run, Alto/Stratocumulus.

7) 15 February 1995, 06Z Run, Organised winter convection.

8) 13th July 1994, 00Z Run, Spanish Plume.

9) 22nd February 1995, 06Z Run. Cold clear winter night following a frontal passage.

10) 26 November 1994, 06Z Run. Stratocumulus.

The results summarised below over all the trials are displayed in terms of forecast time rather than time of day, as both 00Z and 06Z runs were included.

The components of the package connected with the aerosol variable were tested separately from the meteorological components, as they do not have any influence on the forecast evolution. They were tested using two parallel continuous assimilations triggered by the operational suite. The first tested the code changes (i.e. reduced number of advected levels and revised visibility diagnosis) and the second added assimilation of visibility to this.

5. Overall Results

Temperature

The impact on verification results averaged over all cases is shown in Figs 1 and 2. Fig. 1 shows a substantial impact on the midday cool bias resulting from the improvements to the surface layer interpolation. Some improvement in the nocturnal warm bias is also evident, arising primarily from two cases: the 23/11/94 case where the forecast evolution was improved by removing widespread spurious rain, and the 26/11/94 case where the cloud cover was changed by the orographic roughness and diffusion changes. The impact on RMS errors is small but generally beneficial.

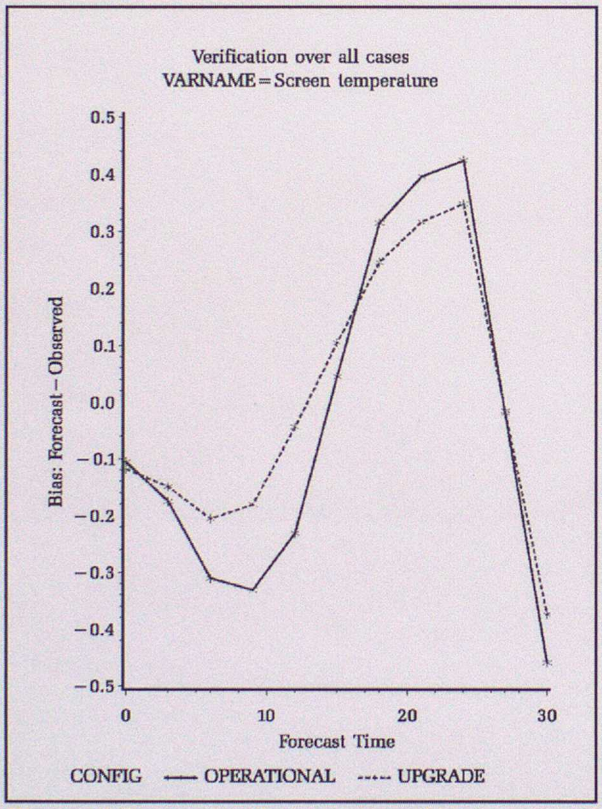

Figure 1 Screen level temperature bias, averaged over all cases.

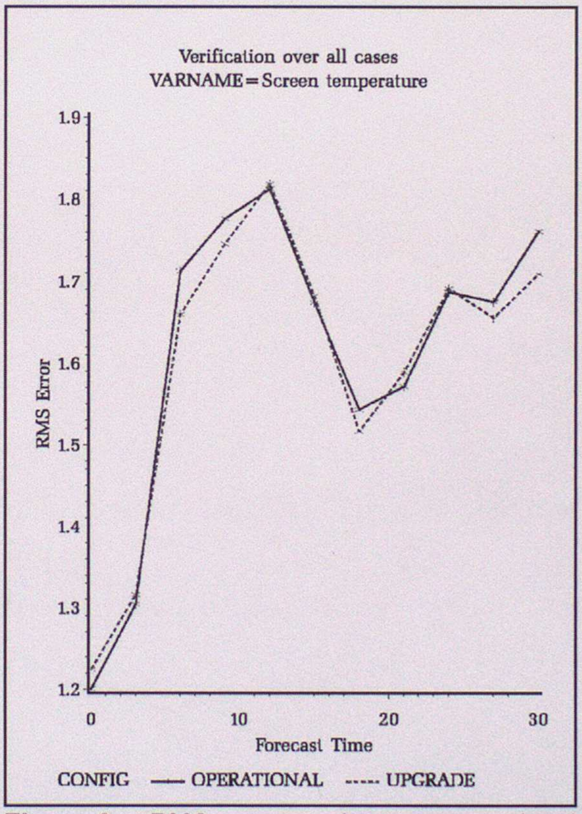

Figure 2 RMS error in screen level temperature, averaged over all cases.

The main impact in the overall verification comes from the two summertime clear sky cases. The bias in verification figures for these two cases is shown in Figs 3 and 4. The improvement in one case is very straightforward, the midday minimum being largely removed. In the second case the improvement is still significant but reduced somewhat by changes in the development during the afternoon.

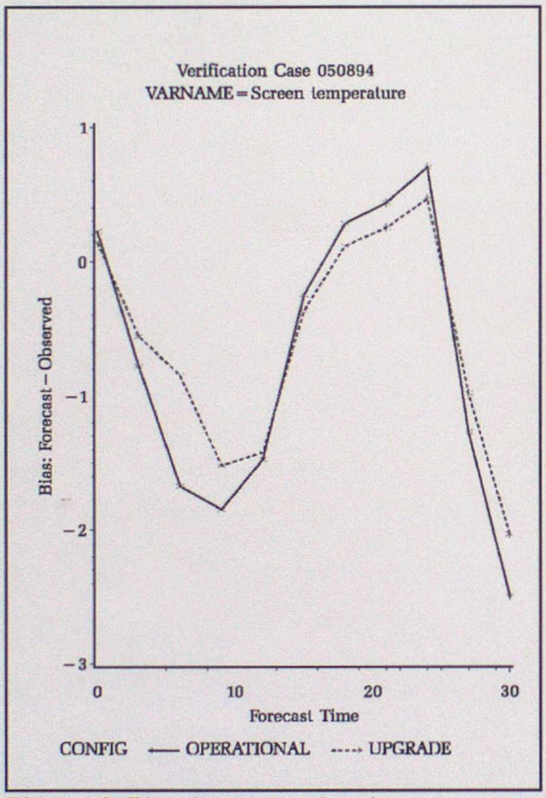

Figure 3 Bias in screen level temperature, 06Z Run 5/8/94.

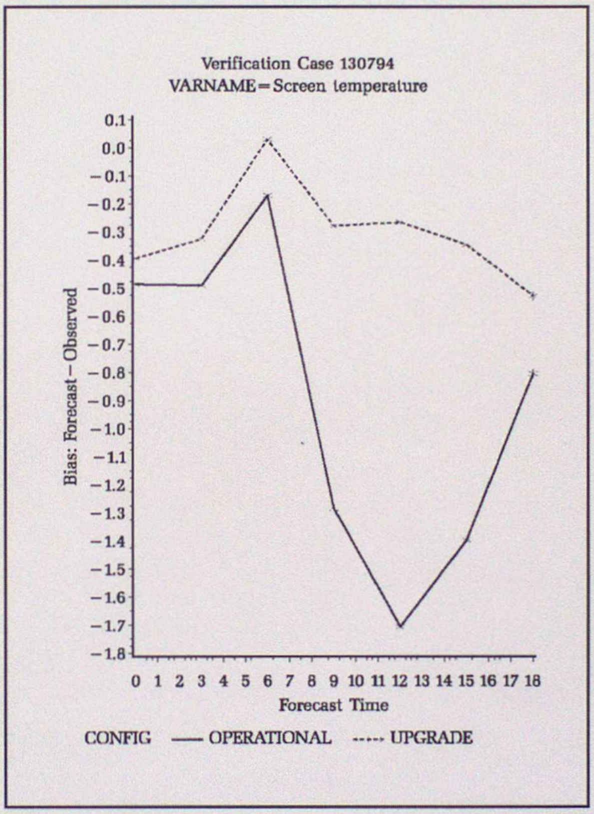

Figure 4 Bias in screen level temperature, 00Z run on 13/07/94.

Wind Speed

In most cases, there is a general strengthening of the 10 m windspeed *diagnosed* from the model. There is a fairly consistent increment in the bias in most cases of between 0.3 and 0.5 m/s. In some cases this leads to a slightly better bias and in others a worse one, but in all cases the RMS error shows either an improvement (typically of 0.3-0.5 m/s out to T+12 and sometimes beyond), or a negligible change. In no cases are the RMS windspeed errors significantly worse. The results averaged over all cases are summarised in Figs 5 and 6. Although the nocturnal bias is worse, the RMS error is improved throughout and the daytime bias also improved. These figures are dominated by the cases involving strong winds, particularly the 17/01/95. In this case the bias was made more positive, but was small compared with the overall strength of the winds. Even in this case the RMS error was improved.

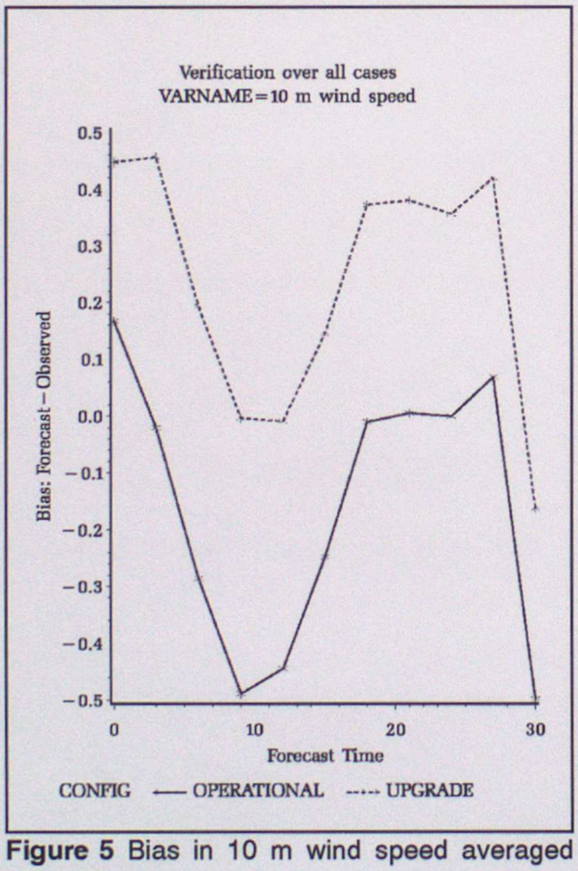

Figure 5 Bias in 10 m wind speed averaged over all cases.

Figure 6 RMS error in 10 m windspeed averaged over all cases.

Relative Humidity

The verification figures show that in most cases the impact of the upgrade package is negligible. When averaged over all cases, there is in fact a marginal deterioration, amounting to, at worst, a 0.3% increase in RMS error at T+9 (i.e. an error of 10.5% becomes one of 10.8%), reducing to 0.1% later. However, this largely arises from the two fog cases, which generally verify better when fog is considered, (see below), so the small deterioration is regarded as not significant. In one case there is a substantial improvement in verification arising from the removal of substantial amounts of spurious rain (Figs 7 and 8). The changes to the diagnosis of screen level q and T in unstable conditions result in negligible impact on the verification figures.

Figure 7 Bias in screen level RH from 06Z run on 23/11/94.

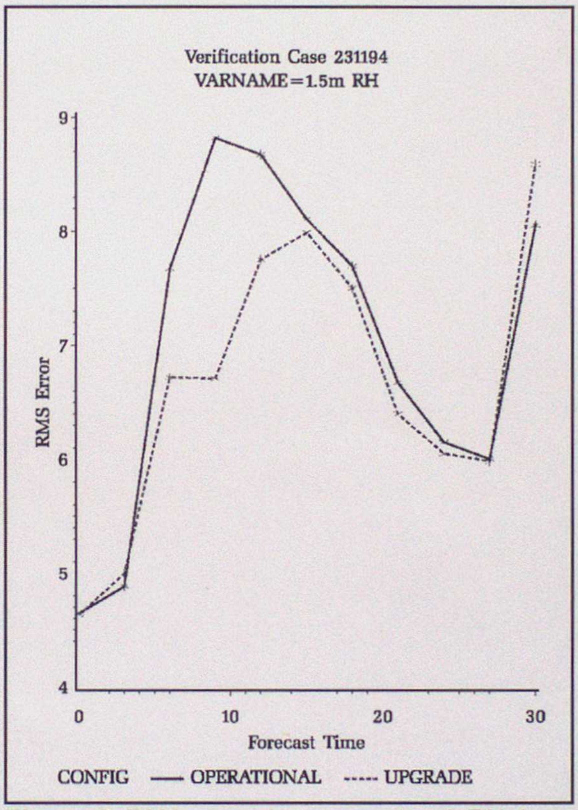

Figure 8 RMS error in screen level RH from 06Z run on 23/11/94.

Cloud

With the exception of the 23/11/94 case, where substantial amounts of mid-level cloud were (correctly) removed by the MOPS change, the impact on cloud cover is small. The overall figures for total cloud are shown in Figs 9 and 10. They are, in fact, marginally worse, though the difference is probably not significant, RMS errors being increased by at most about 0.1 okta.

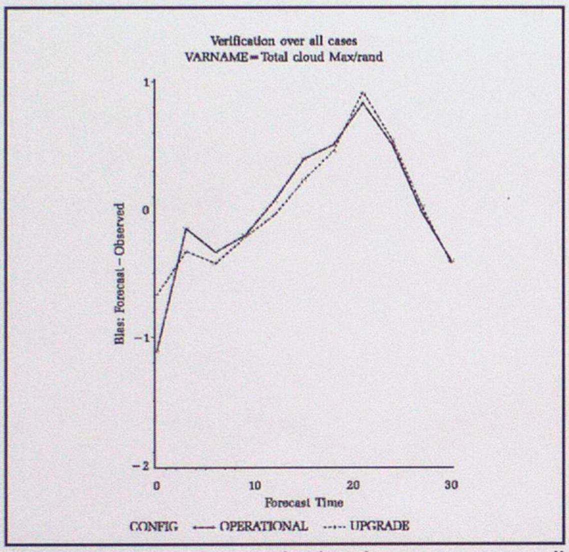

Figure 9 Bias in total cloud cover over all cases.

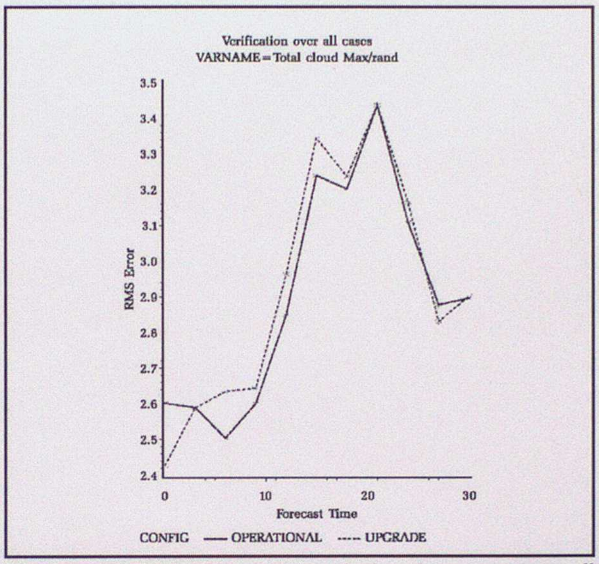

Figure 10 RMS error in total cloud cover over all cases.

The convective cloud cover error averaged over all cases is also affected very little, and the changes are so small they are not shown here. Changes in bias are less than 0.1 okta, and the RMS error in cover is not increased at any forecast time, and is generally smaller, though by only a small amount up to 0.05 oktas. There is, however, a dramatic improvement in the 23/11/94 case in which spurious mid-level convection was produced. This is shown in Figs 11 and 12.

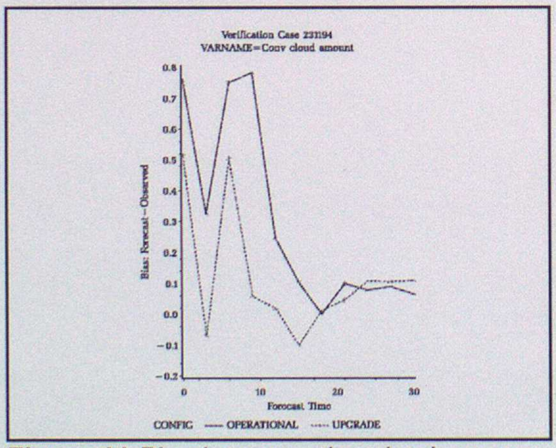

Figure 11 Bias in convective cloud cover on 23/11/94.

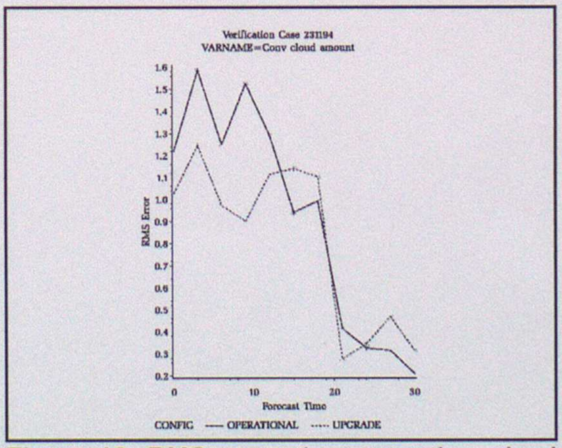

Figure 12 RMS error in convective cloud cover on 23/11/94.

Precipitation

In most cases, little or no impact was anticipated in precipitation, and in most cases this was the result. Precipitation charts from the frontal case of 17/1/95 were, to all intents and purposes identical, any differences being confined to slightly different intensities in isolated grid squares, which would be impossible to verify. Similar comments hold for the frontal band that moves in late in the 06/10/95 case. There is a greater apparent impact in the wintertime convection case (15/2/95), in that the detailed shower distribution is slightly, not surprisingly, different, but the guidance in terms of the general distribution and overall penetration of showers inland at different times is unchanged. The only cases in which there is a significant impact are the 13/7/94 and 23/11/94.

The former case was used as one of the null trials for the MOPS change, as it was a case which operationally produced an 'impressive' improvement on the LAM, successfully forecasting a shower band absent from the LAM as a result of MOPS. The forecast from the proposed package retains these features, and, in fact, slightly improves the shower distribution, as shown in figs 13 to 15.

The 23/11/94 case was a classic example of the error the MOPS change was designed to remove, in that mid-level cloud was falsely diagnosed in the MOPS analysis, and the assimilation of this cloud resulted in widespread mid-level convection and rainfall. The impact of this is illustrated by figs 16-18. It is clear from these figures that the spurious rainfall area is removed while the genuine frontal precipitation to the north is largely unaffected.

In a further two cases of spurious mid-level convection, where the MOPS change was tested alone, significant reductions and removal of spurious rain were noted. In a third case, where convection did take place in reality, there was little impact from the change.

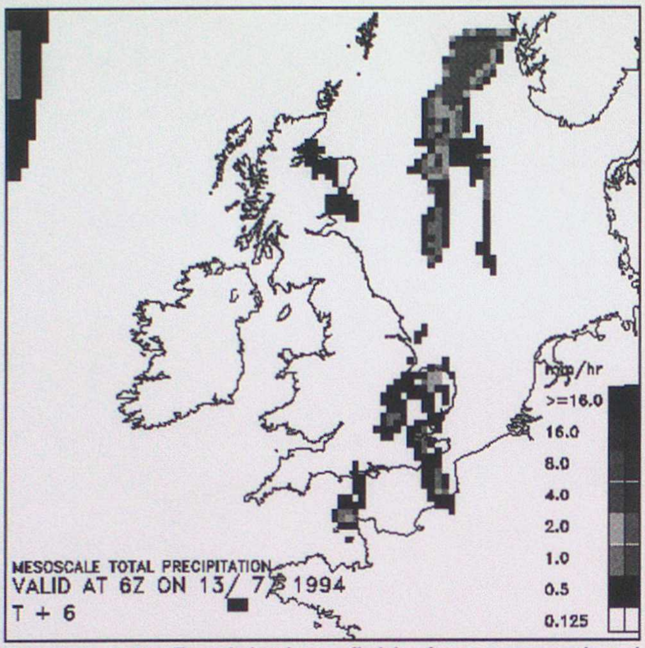

Figure 13 Precipitation field from operational configuration at 06Z, 13/7/94, from 00Z run.

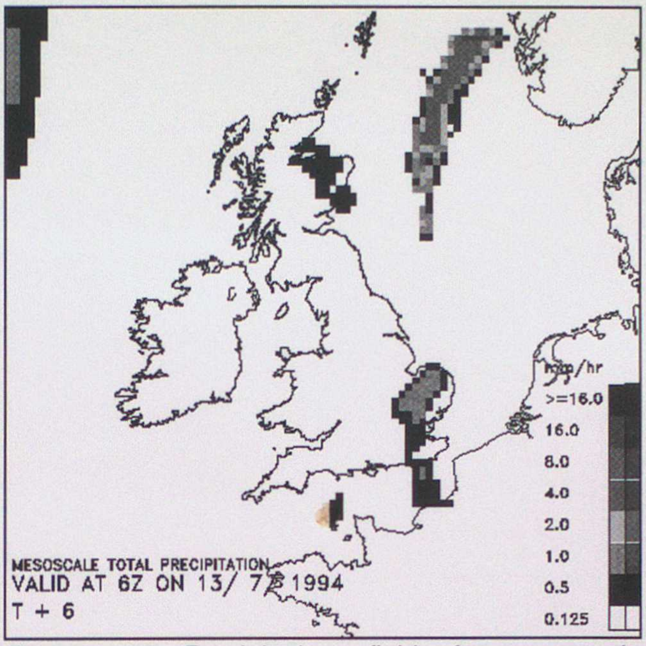

Figure 14 Precipitation field from upgrade configuration at 06Z, 13/7/94, from 00Z run.

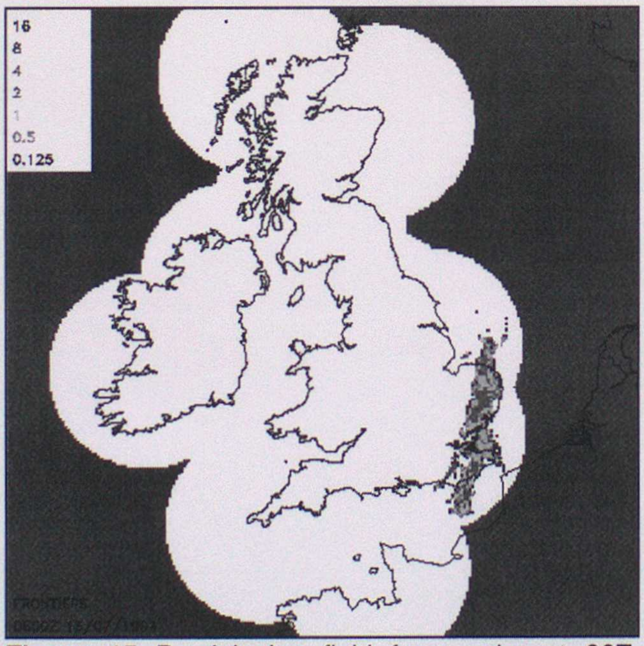

Figure 15 Precipitation field from radar at 06Z, 13/7/94.

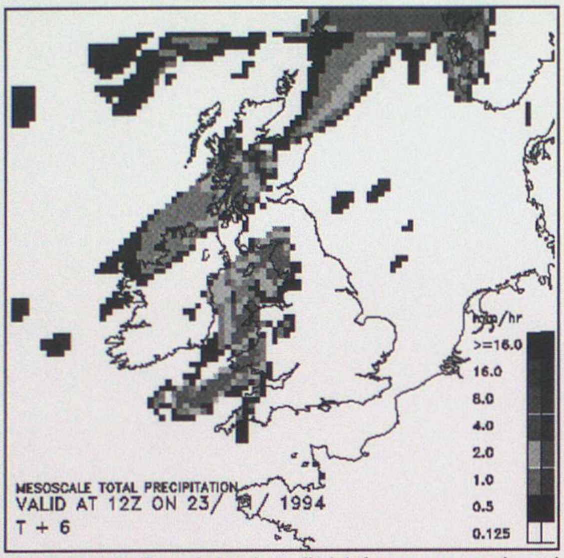

Figure 16 Precipitation field from operational configuration at 12Z, 23/11/94, from 06Z run.

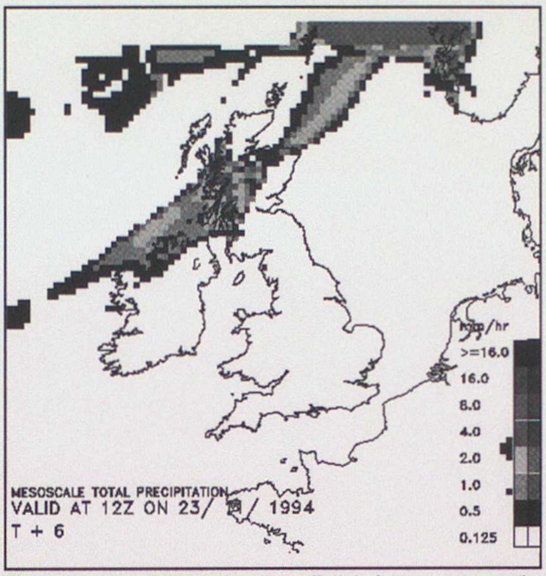

Figure 17 Precipitation field from upgrade configuration at 12Z, 23/11/94, from 06Z run.

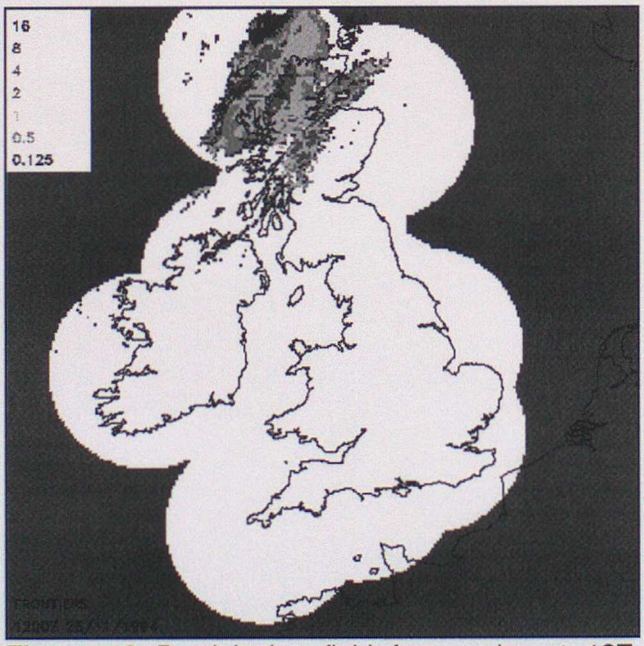

Figure 18 Precipitation field from radar at 12Z, 23/11/94.

Fog and low cloud

Two cases were selected specifically to test the fog performance of the model. Both were cases in which the operational performance had faults. The impact of the package is generally small in both cases. The fog probability distribution is similar, but there are subtle changes in that the upgraded model is able to hang on to small areas of fog blocked by orography rather better. This is largely a result of the improvements to the diffusion scheme. The small but significant differences are illustrated in figs. 19 and 20. There is additional (and correct) indication of fog over the Southern Scottish uplands and off the east coast of Scotland. The difference in fog distribution around the Welsh borders and south coast are also particularly noticeable.

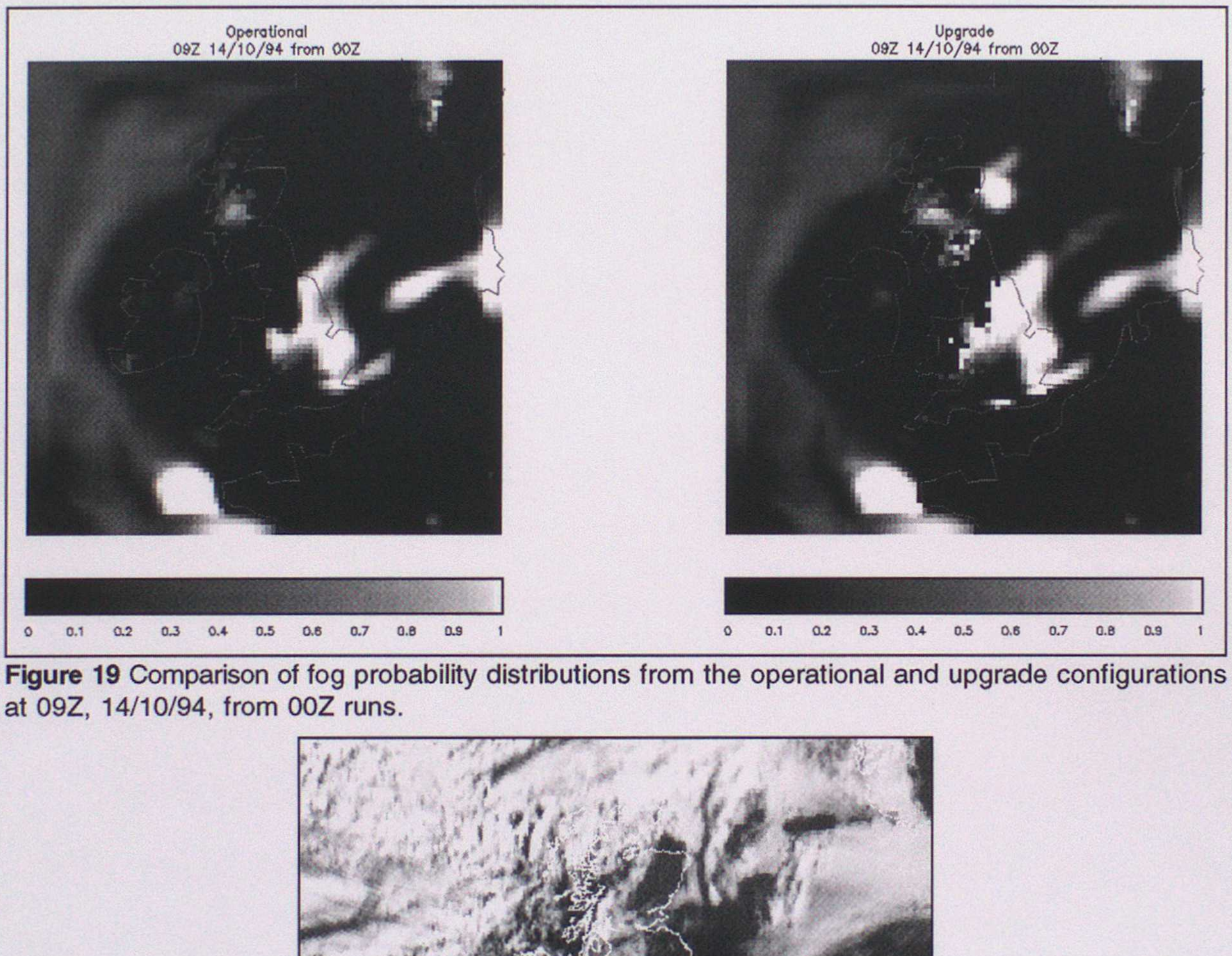

Figure 19 Comparison of fog probability distributions from the operational and upgrade configurations at 09Z, 14/10/94, from 00Z runs.

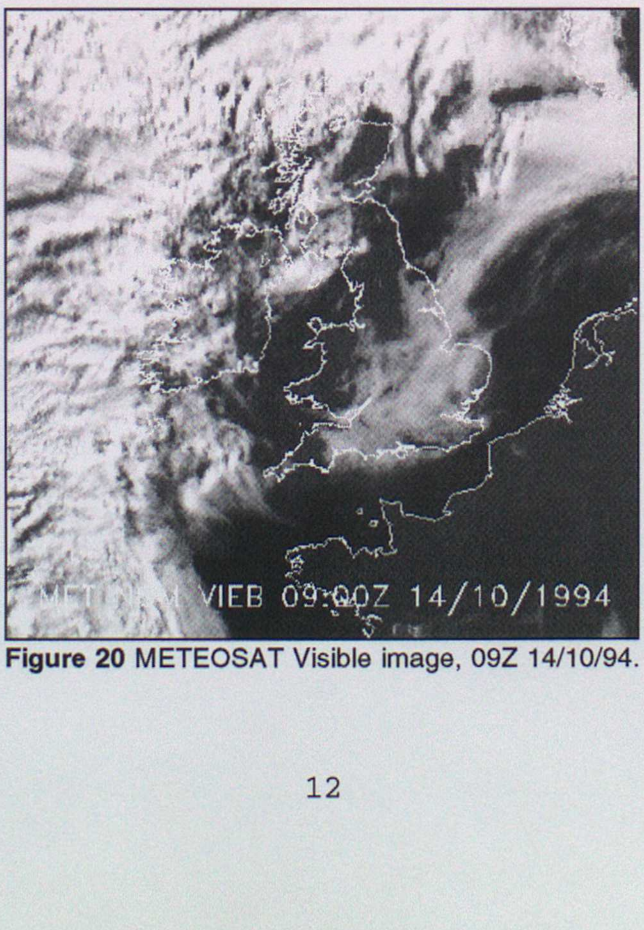

Figure 20 METEOSAT Visible image, 09Z 14/10/94.

The area-based objective verification reflects these small changes. The 8/10/94 forecast shows no change on the successfully forecast areas, but shows a reduction in false alarms by 1 at T+0, 18, 21 and 24 (the period of interest). The 14/10/94 case holds on to fog slightly longer, resulting in an increase in hit rates by 1 at T+9, although this is offset by an extra false alarm at T+18.

Other cases contribute to the objective verification of fog and stratus. The impact has been largely to reduce the number of false alarms while maintaining (and slightly improving) the hit rate, thus improving the overall skill.

Area Based Fog Verification, averaged over all cases.				
Forecast Time (h)	Operational Configuration		Upgrade Configuration	
	Hit Rate (%)	False Alarm Rate (%)	Hit Rate (%)	False Alarm Rate (%)
0	100	56	100	56
3	100	56	100	43
6	100	33	100	14
9	44	20	56	0
12	100	80	100	80
15	100	89	100	89
18	0	100	0	100
21	0	100	0	100
24	40	80	40	82
27	100	83	100	83
30	0	100	0	100

The poor performance at later forecast times results largely from the 5/8/94 hot summer day case, which produced spurious fog overnight both operationally and in the trial. In this case, the spurious fog distribution is different in the trial but the overall guidance equally poor.

Low cloud area based statistics show a similar pattern, except that a reduction in false alarm rate at T+0 and T+3 is accompanied by an equal reduction in hit rate. The results are summarised in the table below:

Area Based Low Cloud Verification, averaged over all cases.				
Forecast Time (h)	Operational Configuration		Upgrade Configuration	
	Hit Rate (%)	False Alarm Rate (%)	Hit Rate (%)	False Alarm Rate (%)
0	73	15	67	9
3	64	44	57	33
6	62	33	62	20
9	56	50	67	33
12	57	50	57	50
15	0	100	0	100
18	0	100	0	100
21	50	89	50	90
24	0	100	0	100
27	0	100	0	100
30	100	80	100	80

Overall, the impact on low cloud performance is fairly neutral.

Changes to the visibility diagnosis system

In September 1994 an aerosol variable was implemented in the operational model to improve the analysis of visibility. Routine verification has shown that the derived visibilities are consistently over-forecast. This may be adjusted by changing the parameters used to diagnose visibility, which were originally chosen to equal those of the old mesoscale model. From the routine verification statistics the visibility analysis has been adjusted by changing the 'typical' number density from 200 to 500 cm^{-3} and the 'typical' radius from 0.5 to 0.2 μm. The radius is the most important quantity, as the scattering varies as it's square. The facility has been added to the code to apply a diurnal variation in source. The magnitude of this is uncertain and at present the variation has been kept at the small figure of ±10%, with its maximum at midday, until more data have become available over summer months. In all cases this small change has a small benefit.

In addition a cost saving simplification is proposed which restricts the advection, source and sink terms for aerosol to boundary layer levels. This has been tested separately and shows typically an 8% CPU saving with negligible impact on the diagnosed visibility.

The development of the aerosol field relies on the field being passed on from model run to model run, so changes have been tested using two continuous assimilation cycles in parallel with the operational suite. The first included all changes except the assimilation of visibility, while the second added assimilation of visibility to this. The tests ran for a two week period, but forecasts were only run from the analyses for 8 days. Only 00Z forecasts were run. Although only 8 forecasts are included, they cover a wide range of conditions including strong westerlies, snow showers, frontal passages and widespread radiation fog. In all individual cases the changes produced significantly improved results over the current operational configuration, though in the strongest winds improvement from assimilation only lasts between 6 and 9 hours into the forecast. Mean bias and RMS error in log10(visibility) are shown in the following figures. The overall improvement is clear.

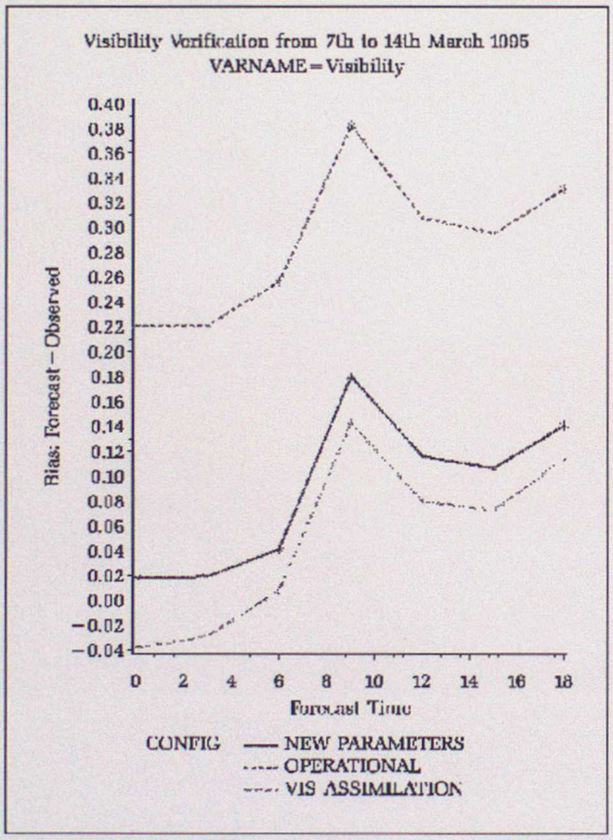

Figure 1 Bias in $\log_{10}$ visibility from parallel 00 Z forecasts between 7 and 14 April 1995.

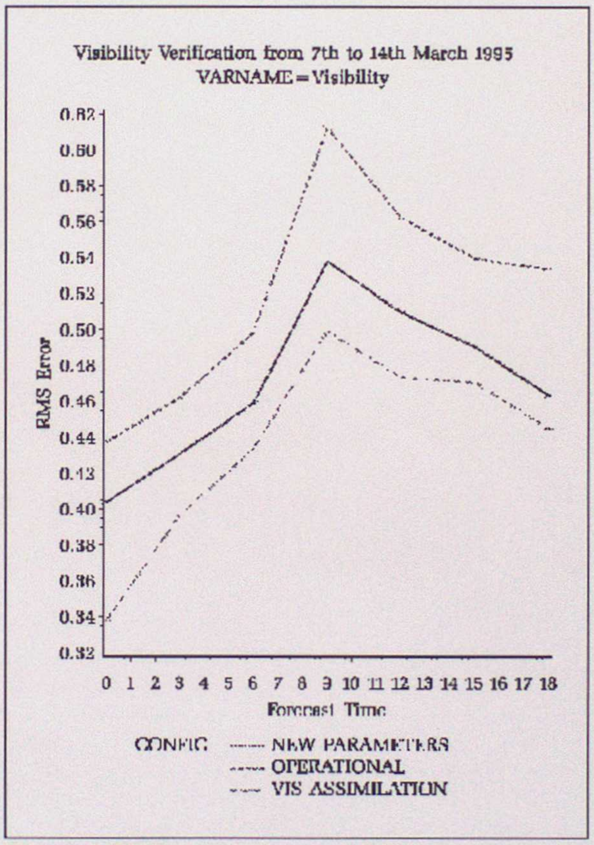

Figure 2 RMS error in $\log_{10}$ visibility from parallel 00 Z forecasts between 7 and 14 April 1995

Impact on the area based fog verification is small, as expected since accurate forecasts of visibilities less than 1 km are generally governed by the relative humidity field. In fact there was one improvement in area based verification as the area with visibility less than 1 km was slightly extended during the fog case, resulting in a more accurate forecast of the dissipation, thereby retaining one fog area that was otherwise missed. The impact on similar figures for visibility less than 5 km is much more dramatic in the one case where a number of areas had visibility less than 5 km but greater than 1 km (13/3/95). The results for this case are summarised in the following table.

Forecast Time (h)	Opertaional		New Parameters plus Assimilation	
	Hit Rate	False Alarm Rate	Hit Rate (%)	False Alarm Rate
0	0	0	0	0
3	0	0	0	100
6	0	0	67	0
9	0	0	100	0
12	0	0	50	0
15	0	0	50	0
18	0	0	50	50

There is clearly still large scope for improvement in the visibility product. Improvements in the source and boundary terms may be made in future, and it is anticipated that improvements to the assimilation parameters will come from a study of OPD statistics. However, there is strong evidence that incorporating the changes will lead to a significant improvement in visibility forecasts.

6. Summary

A package of changes to the physics and assimilation has been tested and implemented in the operational mesoscale model. The main impacts of the package are:

- Daily maximum temperatures in summertime, clear sky conditions are substantially improved by changes to the diagnosis formulation.
- Precipitation is improved by improvements to the MOPS system and improved assimilation parameters.
- 10 m winds are generally improved by changes to the diagnosis formulation and improved assimilation parameters, (primarily related to 10 m wind assimilation).
- Fog probability prediction is improved by changes to the treatment of diffusion.
- Visibility forecasts are improved by changes to the parameters in the diagnosis and assimilation of visibility data.
- More realistic soil moisture is obtained by allowing the soil moisture scheme to free run with improved assimilation of radar rainfall from MOPS.
- Timings are reduced by 3-5% by confining advection, sources and sinks of the aerosol used for visibility diagnosis to the boundary layer levels.

Appendix: a brief summary of cases and the impact of the upgrade package.

Cases

1) 14 October 94 00Z Run, Fog.

Upgrade holds onto fog generally rather better - particularly around S coast and Welsh borders at 09Z. Small impact reflected in area based verification - one extra hit at T+9, one false alarm at T+18. Still deficient to SW. Noticeably different temperature distribution even at T+0. Slightly better RMS RH in morning (during fog) - slightly worse later in forecast. 10 m winds generally up ~0.2 m/s and about 0.1 m/s worse on RMS. Temperature bias ~0.3 degrees better at T+9, worse at T+12, reflecting better fog in the morning but increase in pm. RMS mixed response, but less than 0.1 either way (on ~2.5). Cloud message very variable. If anything the overall impression is slightly worse but not a case where the cloud forecast was important .

2) 23 November 1994 06Z Run, Middle level instability.

Spurious precipitation removed very well - 12Z frame is a good example. RH substantially better.Winds generally up ~0.3 m/s and about 0.2 m/s better on RMS up to T+15. Cloud signal mixed - better where there is full cover. Convective cloud bias down considerably. Area based fog slightly better as fewer false alarms.

3) 17 January 1995, 06Z Run, Frontal rain.

Impact on rain negligible. Roughly 0.8 m/s increase in wind, and RMS improved by 0.2-0.3 m/s. All other variables impact negligible, though tendency to increase cloud in analysis.

4) 5 August 1994, 06Z Run, Clear summer day.

'Hot' area, to E of country substantially warmer - roughly 2 degrees by midday. As a result, sea breeze stronger and more convective cloud and the area cools later on. However, bias in T still improved by 0.8 degrees at midday. Negligible impact on cloud and other variables.

5) 8 October 1994, 06Z Run, Fog.

Fog on the morning of the 9th rather different subjectively, as the main area of fog associated with the old front over central England is less extensive but there is evidence of patchy fog further south. This, in fact, is closer to the truth but the signal is not strong enough to have made a substantial impact on guidance. Area based results are slightly better because of fewer false alarms. RH bias and RMS slightly higher around midday - thereafter better. Slightly worse RMS Temperature error (~0.1 degree) after 18Z.

6) 6 October 1994, 00Z Run. Alto/Stratocumulus.

Slight RH bias and RMS (~0.2%) improvement. Wind speed increased by around 1/2 m/s, impact on RMS mixed : worse early on, better later. RMS temp a little better later in forecast (around midday). Cloud signal mixed - generally better total cloud, but bases may not be as good. Negligible impact on precipitation.

7) 15 February 1995, 06Z Run. Organised winter convection.

Negligible impact except winds ~0.5 m/s higher, so bias more even and RMS improved by ~0.5 m/s. Essentially identical shower distribution.

8) 13th July 1994, 00Z Run. Spanish Plume.

Removal of spurious initial precipitation by MOPS analysis. Shower activity much the same, but subjectively slightly better later in forecast as spurious showers are removed to the west of the main area. Dramatic improvement in temperature bias (~1.5 degrees).

9) 22nd February 1995, 06Z Run. Cold winter night following a frontal passage.

This was tested to insure there is no detrimental impact for T+24 frost forecasts. Negligible impact.

10) 26 November 1994, 06Z Run. Stratocumulus.

Substantially less initial rain verifies better. Later in forecast slightly tighter gradients on front. Showers penetrating slightly further inland. Little impact on most objective stats except fog not quite so bad, temperature marginally worse RMS later in the forecast. Total cloud sustantially worse (increase in RMS of 1 okta) between T+9 and T+18.