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ABSTRACT

The configuration and formulation of the new mesoscale model (NMM), a version of the Unified Model, is described and contrasted with its predecessor, the original non-hydrostatic mesoscale model (OMM). The results of an initial trial in Spring 1992, over 8 test forecasts, of the mesoscale configuration of the unified model using the same basic system as used in the operational Limited Area Model (LAM) are briefly described. This highlighted areas where further development was required before the new model could match the performance of the OMM . In particular surface roughness lengths for momentum taking into account the effects of hedges, trees, buildings and subgridscale orography (as used in the OMM) were required rather than values based on the main vegetation type (specified as grass in the unified model) to match the skill of 10m wind prediction. The basic unified model had a deficiency in the prediction of convection over land compared with the OMM and the observations but improvements to the surface roughness scheme, boundary layer scheme and in particular the convection scheme (to include parametrisation of downdraughts as well as updraughts) have brought the performance of the model up to a satisfactory standard for operational implementation on 8th December 1992.

This paper concentrates on the development and performance of the model itself. A companion paper by Macpherson et al 1993 describes the data assimilation scheme and its performance.

1. Introduction

The UK Met Office has been routinely running a mesoscale NWP forecasting system since 1985 (Golding 1990). This was originally based on a non-hydrostatic model (Tapp and White 1976) with a continuous but intermittant initialisation, the Interactive Mesoscale Initialisation (Wright and Golding 1990). The major problem with the original mesoscale forecasting system (OMM) was the initialisation scheme which resulted in excessive convective precipitation and loss of gridscale cloud at the start of the forecast (Ballard 1991).

In July 1991 the Meteorological Office replaced its operational Global and regional (limited area model - LAM) models with versions of a new model, referred to as the Unified Model (Cullen 1991,1993), which is also used as the Climate Model in the Hadley Centre. The Unified Model contains more sophisticated parametrizations of physical processes than the previous larger scale operational models and so is much more similar to the nonhydrostatic mesoscale model and has the additional benefit of a full data assimilation scheme which should remove many of the initialisation problems. Therefore a high resolution version of the Unified Model (NMM) has been developed and this replaced the original mesoscale (OMM) forecasting system for the production of operational forecasts for the British Isles area on 8th December 1992.

The 'unification' of the mesoscale forecast system simplifies the maintenance of the operational suite and allows developments in formulation of models to be immediately available for use in all configurations - from climate to mesoscale resolutions.

This paper describes the development of the new mesoscale model and its performance in pre-operational trials in comparison with the original mesoscale model and observations. Section 2 describes the configuration and formulation of the first test version of the new model and compares it with the original model. The results of a preliminary trial are described in section 3 and the developments required to allow the NMM to match the performance of the OMM in section 4. Section 5 describes the results of the second pre-operational trial and section 6 summarises the conclusions.

2. Differences in Configuration and Formulation of the Old and New Mesoscale Models

2.1 Domain and Resolution

The configuration chosen for the new mesoscale model was designed for data assimilation experiments and to minimise development work in the first year. It has not necessarily been optimised to fulfill all the requirements of the original model, in particular prediction of fog.

The OMM used a transverse mercator projection (UK national grid) with 15km gridlength. Limited area versions of the unified model use a lat/lon grid with a rotated pole to reduce variations in gridlengths within the domain. A pole of 37.5N 177.5E and gridlength of 0.15° (16.8km) was chosen for the NMM with 92x92 gridpoints. This area is slightly larger than for the old model and the domain and gridpoints are shown in figure 1 within a subdomain of the LAM.

The OMM used height above orography for its vertical levels whereas the unified model uses hybrid sigma/pressure coordinates , see figure 2. The OMM had 32 levels with a top of 14km whereas the operational version of the NMM has 30 levels and the LAM has 19 levels, both with a top of 4.6mb. 31 levels were used in the trials of the new model as the LAM had 20 levels at that time. The NMM has the same levels as the LAM above 8km but increased resolution below that height to provide better resolution of thin stratocumulus cloud as in the OMM. However to avoid any potential difficulties with very fine vertical resolution the resolution of the NMM is not as high as the OMM near the surface and the bottom level has been kept the same as the LAM. This means that the 10m wind and screen temperature are now diagnosed rather than directly predicted variables. Model level heights for the OMM and NMM and the LAM are compared in figure 3, where the heights shown for the NMM and LAM are approximate.

2.2 Dynamics

The NMM is hydrostatic with a split-explicit time integration scheme, 2nd order Heun centred differencing, forward time-differencing with forward-backward adjustment steps and uses a B-grid staggering and 90sec time-step. The OMM was non-hydrostatic with semi-implicit time integration scheme, 2nd order averaged centred differencing, leapfrog time-differencing and uses a C-grid staggering and 60sec time-step. Both models use 2nd order horizontal diffusion with coefficients of order 4 x 10^4 m^2s^{-2} but the OMM used a reduced value for diffusion of heat and moisture.

2.3 Physical Parametrisations

The main differences are described below.

As with the OMM, the unified model explicitly predicts cloud condensate and the advected variables are total water and liquid water potential temperature. However the microphysics is slightly different in its treatment of ice and water phases of cloud and precipitation. In the OMM the condensate was either water or ice dependent on cloud top temperature whereas in the unified model between -15°C and 0°C both water and ice are assumed to be present and the ratio depends on the environmental temperature. Also in the OMM falling snow only started melting when the wet bulb temperature rose above freezing whereas in the unified model this occurs when the environmental temperature is above freezing.

In the unified model vertical mixing is only applied in the boundary layer, which in the first trial of the NMM was set to have a maximum specified depth of 10 levels, and uses a 1st order stability dependent scheme rather than the 1.5 order TKE scheme which was applied at all levels in the OMM (Ballard et al 1991).

The unified model has fully interactive multilevel short-wave and long-wave radiation schemes with specified update frequency, three-hourly in the LAM and global models. The OMM had a fully interactive long-wave radiation scheme which was updated every 1/4hour whereas solar fluxes were only calculated at cloud top and the surface but were updated every time-step. For consistency with the OMM the update frequency in the NMM was set to 1/4hourly for the first trials.

The convection scheme in the unified model is an instantaneous penetrative mass flux scheme dependent on the bouyancy of the lowest 2 levels which transports heat and moisture but does not yet transport momentum. In the initial version of the unified model this scheme included parametrisation of updraughts but not downdraughts. The scheme in the OMM assumed a cloud life-time of 1hour in which the convective cloud was advected with the mid-level wind, it had a CAPE closure, formulation in terms of mass sources and sinks, transport of heat, moisture and momentum and treatment of downdraughts as well as updraughts. In the OMM some gridscale cloud and upward vertical velocity had to be present before the convection scheme could be triggered which essentially ensured that only the TKE scheme would do boundary layer mixing whereas in the unified model both the convection scheme and the boundary layer scheme can be involved.

2.4 Land surface processes and characteristics

There are many differences in the treatment of land surface processes between the two models and the unified model has a potentially more sophisticated scheme. Some of the main differences are that the new model has a 4 layer soil model as opposed to 2 in the old model, there is treatment of canopy hydrology in the NMM but not the OMM, the NMM has a fixed surface resistance to evaporation but with soil moisture predicted each timestep whereas the OMM has a slightly different formulation where the effects of the surface resistance to evaporation and soil moisture content are effectively combined in one variable which is updated weekly from analysis of observational data on a 40km grid (MORECS soil moisture deficit). In the new model surface and soil characteristics such as albedo, thermal conductivity and heat capacity are specified based on 1° resolution source data of vegetation and soil type. This gives grass cover for the British Isles and albedo values typically between 0.17 and 0.19. In the old model uniform soil characteristics and surface albedo (0.18) were assumed. In the unified model the surface roughness length is based solely on the vegetation type whereas the old model took account of subgridscale orographic variations, buildings etc, see section 4. In addition to the use of MORECS data some points, such as London and Birmingham, in the old model were defined as urban and a high surface resistance to evaporation 500 cm^{-1} was always set. This meant that there was some simulation of the urban heat island effect which is missing in the new model. In the initial trials of the new model the orography and land/sea mask was derived from the 10' data used for the other configurations of the unified model whereas 5' resolution source data was used to derive the orography for the old model.

2.5 Initialisation and data assimilation

The old mesoscale model was run operationally to produce two main forecasts per day for 18 hours from 00Z and 30 hours from 06Z and used boundary conditions produced from LAM forecasts with the same data time.

The OMM had a three hourly intermittant forecast and initialisation cycle so that initial conditions were produced by using surface observations , radar and satellite imagery under forecaster control to modify the boundary layer and cloud and humidity structure of background fields produced by merging the latest LAM analysis or forecast with a 3 hour mesoscale forecast (Wright and Golding 1990). This meant that conventional upper air data only entered the mesoscale model through the use of the LAM fields in the background and radiosondes were not assimilated at the higher vertical resolution of the mesoscale model. However it did mean that mesoscale detail in atmospheric and surface fields was passed from forecast to forecast. The IMI made use of reports of screen temperature, screen humidity, 10m winds, pmsl, visibility, cloud base, cover and type, surface weather reports interpretated as precipitation rates as well as satellite derived cloud amounts and tops and radar rain rates to initialise the initial fields. A snow depth analysis was also used and forecast values were used as background.

The unified model uses the Analysis Correction Scheme (Lorenc, Bell and Macpherson 1991) for continuous assimilation of observations over a period at the start of the forecast by nudging the predicted values of wind, temperature and humidity towards the observed values. For the 0000Z/0600Z NMM forecast runs T-6 hours limited area/global analyses valid for 1800Z/0000Z are interpolated to the mesoscale grid and forecasts, including assimilation of data in the period T-6 to T+2, are run out to T+18/T+30 hours using boundary conditions from the LAM assimilation and forecast for the same data time. In the initial trial only data available to the LAM was assimilated but they were processed to the higher vertical resolution of the NMM. The LAM uses pmsl, 10m wind over sea only, radiosonde ascents of temperature, humidity and winds, satellite sounding data and aircraft reports. The NMM essentially has two independent forecasts starting each cycle from coarser resolution fields and so only has a six hour spin-up period to the higher resolution before the start of the forecast. There is no snow depth analysis so the model essentially starts from fields produced by the global and LAM assimilation cycles.

3. Results from the Initial Trial in Spring 1992

3.1 Definition of Trial 1

The performance criteria set for the NMM was that it should match or better the skill of the OMM in prediction of screen temperature, 10m wind, cloud and precipitation. Skill in prediction of fog and visibility was excluded from the assessment as it was felt that too much work would be required to adapt the model to perform adequately in the time available, less than one year. Initial trials of 8 cases were run in March 1992 using the basic unified model at Vn 2.4, ie the version used operationally for the LAM and global models at that time. The 8 cases were selected to cover mesoscale issues:

0Z 6/7/91 thunderstorms ahead of low pressure system in SW approaches - poor operational forecast thunderstorms too late. Selected to test ability of assimilation/initialisation to correct evolution errors

0Z 23/8/91 fine-scale spiral rainbands associated with low centre moving NEwards across UK - good operational mesoscale forecast. Selected to test ability of new model to add detail to LAM forecast.

0Z 1/9/91 hottest day, anticyclone N Sea, low over N France coast - good operational mesoscale forecast. Selected to test skill in distribution of maximim temperatures.

0Z 8/9/91 sea breezes, anticyclone centred on UK - reasonable operational mesoscale forecast. Selected to test skill in local wind prediction.

6Z 8/11/91 Cheshire gap convective cloud and rain band, cold NWrly airstream following transition of front - good operational mesoscale forecast. Selected to test skill in prediction of topographically forced convection.

0Z 4/12/91 stratocumulus, anticyclone centred over UK - poor operational mesoscale forecast due to IMI problems. Selected to test skill in low cloud prediction and impact of assimilation/initialisation.

6Z 11/12/91 coldest night, ridge over southern UK, freezing fog - poor operational mesoscale forecast as too much cloud so minimum temperatures too high on second night. Selected to test skill in minimum temperature prediction.

6Z 14/12/91 freezing fog, ridge over southern UK - reasonable operational mesoscale forecast as fog initialised and retained throughout day but too much in second night. Selected to test skill in fog prediction.

Figure 4 shows the analysed pmsl for 12Z for the 0Z cases and 0Z for the 6Z cases.

Comparisons were made between forecasts with same datatime for each case:-

Limited area model, LAM, with assimilation - referred to as LAMAC
New mesoscale model, NMM with assimilation - referred to as NMMAC
NMM from interpolated LAM analysis - referred to as NMMLAM
current mesoscale model from interpolated LAM analyses - referred to as OMMLAM
operational mesoscale forecast - referred to as OMMIMI.

As mentioned in section 2 in this initial version the short and long wave radiation schemes were called every 15 minutes, as is done for the long-wave scheme in the current mesoscale model. The orography was derived from the 10' resolution basic data used for the other versions of the unified model. The new model had 31 levels as the LAM had 20 levels at that time. The timestep and horizontal diffusion coefficient was set to give stable forecasts at the resolution of the new model. The bottom 10 levels were included in the boundary layer schemes and all the surface characteristics were derived from the 1° resolution data used for the LAM and global models.

Examination of the forecasts indicated that further development was required if the NMM was to add value to the LAM in the way that the OMM did. In particular effort was required to reduce wind speed errors over land, improve prediction of convection over land, provide more detail in screen temperature predictions through use of higher resolution surface characteristics and to improve the quality of forecasts of fog and visibility . Summarised conclusions are given below.

3.2 Wind

The most obvious difference was the accuracy of wind speed and direction forecasts. The mean and RMS errors for speed and mean error for direction were much higher in the basic unified model (LAMAC, NMMAC,NMMLAM) than the current operational mesoscale model (OMMLAM and OMMIMI). This is consistent with the higher roughness lengths used in the latter model and work has been undertaken to implement use of the OMM roughness lengths in the NMM, see section 4 . Sea breezes were captured by all models but details depended on resolution and possibly surface characteristic differences.

3.3 Temperature

The relative objective skill between OMMIMI and NMM forecasts from T+6/T+9 onwards varied between cases with honours shared roughly equally overall, either model often coming out better for a complete forecast period . Signs of biases varied between cases and models as well with no overall clear signal. Generally the NMM and LAM started too cold, detail increased from LAMAC to NMMAC to OMMIMI but the OMM skill was often reduced due to errors in cloud forecasts in part of the domain. Increased detail in OMMIMI is probably due to surface characteristics - possibly soil moisture in the daytime. OMMLAM suffered due to limitations of the interpolation method used to derive initial fields, this gave a negative bias (forecasts from 12Z or 18Z may have positive biases).

3.4 Precipitation

The unified model did not forecast the inland penetration of bands of convection through the Cheshire Gap which is captured well by the OMM model (Ballard 1989 and 1991). Over sea the unified model predicted blanket convective precipitation whereas the old mesoscale fields showed more structure. The unified model generally did not predict convection over land unless it had strong dynamical forcing as in the thunderstorm case where it did match OMM performance although both had poor evolution. The NMM and OMM both show more structure in the spiral precipitation bands in the cyclonic case than the LAM, see figure 5. In general the extra detail from the increased horizontal resolution appears more dramatic in the OMM but a larger areal coverage of precipitation in the NMM may give better skill scores.

3.5 Cloud

Cloud base charts were not available but from objective verification and cloud cover charts the NMM forecasts were very promising. Some areas of stratocumulus over the sea predicted as full cover gridscale cloud in the OMM came out as shallow convective cloud with small cloud fractions in the NMM and the interaction of the convection and boundary layer schemes in the unified model needs further study. For the stratocumulus case, see figure 6, the OMMIMI run was very poor due to IMI problems and OMMLAM gave much better cloud prediction. The LAMAC was also better than the OMMIMI but erroneously predicted widespread cloud in level 1 (ie fog) in an otherwise cloudfree area from north of the Wash to central Scotland. The NMM forecasts were better than the LAM as they did not predict the spurious fog and the NMMAC was slightly better than NMMLAM.

3.6 Fog

Visibility could only be diagnosed at screen level or model level 1 (25m) in the unified model. Initially visibility was diagnosed at model level 1 and compared with forecasts from the OMM which used the 5m level. There is no visibility or screen relative humidity analysis in the unified model. There is also no initialisation or advection of boundary layer aerosol in the unified model and so a constant value of 200 cm^{-3} is used in the diagnosis of visibilty in the unified model, see Ballard et al 1992. In the freezing fog case the OMMIMI gave a better forecast due to the benefit of the initialisation in the IMI. However it did not maintain enough fog during the day and predicted too much the next morning, although much of this was in areas reporting mist and shallow fog patches. The NMM had no fog during the first morning and day and when it formed fog during the second night it was mainly in the cloudy but fog free west rather than the cloud free east of the UK, see Ballard et al 1992. More development is required on the model and assimilation to match the skill of the OMM.

3.7 Data Assimilation

There was a clear benefit in the NMMAC over the LAMAC and NMMLAM in assimilating radiosondes at higher vertical resolution, most marked when comparing analysed ascents but on occasion visible well into the forecast, see figure 7. Spin-up of precipitation over land was noted in the NMMAC run in a couple of cases but no worse than in LAMAC. In the 23/8/91 case a forward rainband at T+12 was only predicted in the OMMIMI forecast, an impact from IMI, see figure 5. In the 14/12/91 case there was obvious benefit from the cloud , low level humidity and visibility analysis as the OMMIMI was the only run to forecast the fog during the first morning and day. However the IMI had an unreliable impact on low cloud forecasts in general, in particular producing a poorer forecast of the stratocumulus evolution on 4/12/91 than the OMMLAM, see figure 6. However in that case the OMMLAM, NMMLAM , NMMAC and LAMAC were all deficient in stratocumulus over land at analysis time. Screen temperature scores from the OMMIMI run were consistently better than the NMMAC ones to T+3 showing the benefit of the use of screen temperature data to adjust the low level temperature structure in the OMMIMI as well as the use of the 3 hour mesoscale forecast in the first guess. The screen temperature scores were of comparable accuracy by T+6 and T+9. By comparing OMMIMI and OMMLAM forecasts any impact from analysing 10m winds over land also seems to have been lost by T+6/T+9.

4. Development of new mesoscale model

4.1 Introduction

Following the initial trial work was undertaken to improve the performance of the mesoscale version of the unified model. Development work on the model formulation concentrated on reducing the bias in the 10m winds and improving the prediction of precipitation. The unified model assimilation scheme was extended (Macpherson et al 1993) to include the assimilation of screen temperature and 10m winds over land and 3D relative humidity profiles derived from a 3D cloud cover analysis produced by MOPS (Moisture Observation Pre-Processing System - the interactive successor to the IMI but now only producing a cloud cover analysis , Wright 1993). As mentioned in section 3 it was decided that no effort would be put into optimising the new model for fog prediction until after operational implementation. This section describes the work undertaken and summarises some of the impact of the modifications to the model.

4.2 Maximum number of Boundary Layer Levels

In a case study investigation of the boundary layer fluxes in the mesoscale version of the unified model (Veitch 1992) it was found that during the day these were still non-zero at level 10 so the boundary layer scheme has been changed to work on the bottom 13 levels which is more consistent with the depth of the 5 layers used in the LAM.

4.3 Surface characteristics

The orography and land/sea mask for the new mesoscale model has been rederived using the 5' resolution data used for the OMM. The new orography and land/sea mask are shown in figures 8 and 9b. The land/sea mask of the OMM is shown in figure 9a for comparison. The method of derivation of orography and land/sea mask is slightly different for the two models and this, plus the slightly reduced horizontal resolution of the new model, means that the coastline is not quite as detailed or accurate as the OMM. However the new model coastline does capture all the essential features .

Apart from the land surface roughness lengths, see section 4.6, and the orography all other surface characteristics are derived from the same data as the LAM and global models.

4.4 Radiation

The frequency of calls to the radiation scheme has been reduced to hourly from 1/4 hourly. This is compared with 3 hourly calls in the LAM and global models. The frequency of calls to the radiation scheme essentially determines the speed of response of model temperatures to changes in the cloud cover as the temperature increments due to radiation at each model level and the surface are calculated at the time of the call to the radiation scheme and then held fixed until the next time it is called. It was found that there was a definite positive impact from reducing the frequency of calls from 3 hourly to hourly. Although there was a further impact from increasing the frequency of calls from hourly to 1/4 hourly it was felt that the increased cost of the more frequent calls was not justified until errors in prediction of cloud were reduced. W Ingram, personal communication, has however modified the short-wave scheme to include an update of solar angle every time-step to reduce errors resulting from infrequent calls.

4.5 Data Assimilation

The unified model data assimilation scheme has been extended to allow assimilation of screen temperature observations and to extend use of 10m wind observations to land. Corrections are applied to low level and surface temperatures based on difference between diagnosed and observed screen temperature after adjusting for differences in orographic height between the station and the model. This is different to the OMM where no adjustment for height difference is made. The OMM analysis also fits the observations more closely than the unified model scheme. The assimilation has been extended to use hourly surface data rather than 3 hourly as used in the first trial and the LAM.

In order to produce better initial cloud in the new model the IMI has been adapted to work on new mesoscale model fields as a first guess for a 3D cloud cover analysis. As before CFO forecasters will be able to intervene on rainfall rate, cloud cover, cloud top and cloud base analyses which are inputs to an automatic 3D cloud cover analysis. No other fields will be analysed in the cut down version of the IMI which now becomes an observation processing system referred to as MOPS (Moisture Observation Pre-processing System, Wright 1993). The 3D cloud cover analysis is used to derive 'soundings' of relative humidity at each model grid point in a manner consistent with the model's cloud scheme. These soundings are then assimilated into the model in the same manner as radiosondes. Due to difficulties in automatically detecting cloud cover and top from satellite imagery for low cloud MOPS can only be safely performed with manual intervention at present . If this cannot be done no additional 'soundings' will be generated for that assimilation cycle. Note that the 3D cloud analysis can be used to force fog into the new model initial conditions if it is treated as shallow cloud with a base at the surface - this is not done automatically at present. The MOPS data are produced at T-3 and T+0 only.

See Macpherson et al 1993 for more details on modifications to the data assimilation scheme.

4.6 Modified Surface Roughness Length Scheme

Code has been developed for the mesoscale version of the unified model to use a surface roughness length scheme similar to that used in the OMM.

The basic unified model has a surface roughness derived from a specification of surface vegetative cover. This comes from a global dataset with resolution of 1° derived for climate studies and gives grass cover for the whole of the UK and subsequently low roughness lengths of about 0.008-0.016m for the UK with a maximum in the mesoscale domain of 0.25m over Norway (from coniferous forests).

In England, Wales and Scotland the OMM used roughness lengths for momentum derived from studies by Smith and Carson 1977. The Smith and Carson 1977 data takes into account the presence of lakes, grass, fields, slopes and buildings (giving roughness lengths of 0.3-0.5m in lowland UK) and for mountainous areas is a form of orographic roughness taking into account the effect of subgridscale peaks and valleys. In the OMM the roughness length was limited to a maximum value of 1m and outside the area of the Smith and Carson data a value of 0.1m was used (the same as in the old fine-mesh and global models). Also in the OMM the roughness length for heat and moisture was reduced to 1/5 the value for momentum and further limited to 0.1m whereas the basic unified model uses the same values for heat, moisture and momentum.

The Smith and Carson roughness lengths have been extracted onto the new mesoscale model grid and again 0.1m has been used for land points where no values are available from the original data. These ,with the reduced roughness lengths for heat and momentum, are now used in the mesoscale version of the unified model and both are separately reduced in the presence of snow cover - the exact roughness length depending on the snow depth. This scheme reduces the wind speed bias in the NMM towards that in the OMM without adversely affecting the screen temperature forecasts, see section 5. The original and new surface roughness lengths for momentum are compared in figure 10.

The use of the OMM roughness length field also improved the prediction of the cloud band in the Cheshire Gap case. This was an observed cloud band penetrating inland in the gap between the Pennines and Snowdonia to reach the Midlands and western edge of east Anglia overnight in a NWrly airstream, see figures 11a,b and 12a. The basic model, as used in trial 1 or with only the modifications described in section 4.2 to 4.5, had some cloud penetrating inland but only for a short time and not far enough inland and convection stopped at the coast, see figures 11c,12c,13a and 14a . With the new roughness lengths the cloud band persisted longer, stretched further inland and some convection was produced on windward facing slopes, see figures 13c and 14c.

4.7 Modifications to Convection and Grid-scale Precipitation Schemes.

A modification has been developed to the unified model convection scheme by D Gregory, personal communication. This includes an extension to include a parametrisation of the effects of downdraughts associated with convective storms. A new formula is also used for the evaporation of rain and snow and the convective (updraught) mass flux has been increased by increasing the initial mass flux, MI.

$MI = 1x10^{-3} \text{ x } C \text{ x bouyancy}/\Delta P$

and C was increased from $3.33x10^{-4}$ to $5.17x10^{-4}$. The formulae used for evaporation of rain and snow in the grid-scale precipitation scheme have also been modified to be consistent with the new convection scheme. This version is referred to as new convection and gridscale evaporation scheme with climate/LAM convection parameters in the figures as this version was adopted for the climate model and introduced operationally in the LAM in April 1993.

Including this scheme in the mesoscale model version increased the convection over land in the cyclonic spiral rainband case, see figure 15c. The basic unified model, see figure 5e, 5f and 15b, did not predict any precipitation in a forward band over land (located between The Wash and the Isle of Wight at 12Z 23/8/91) despite producing it in the band where it was over the English Channel. When the new convection scheme was included there is significant convective precipitation in the correct area over land but slightly less over the sea. There is also more convection over Ireland.

On its own this scheme has little impact on the lack of precipitation associated with the cloud band in the Cheshire Gap case, see figure 13e.

The new convection scheme has a greater tendency to predict snow showers than the original scheme as can be seen by comparison of figures 13a and 13e where it can be seen that most of the convective precipitation to the north of Scotland is in the form of snow in the new scheme. This is due to the fact that the falling precipitation is now only within the downdraught, a small proportion of the grid square, rather than the complete grid area. Now only the downdraught air rather than the complete gridbox is cooled due to latent heat when snow melts so that the downdraught is more likely to be maintained at or below zero and the precipitation will fall in the form of snow rather than rain.

4.8 Modification to Boundary Layer Scheme.

In developing the climate version of the unified model it was felt that heat and moisture was not being transported fast enough away from the surface and a modification to the boundary layer scheme has been developed (Smith 1993). In addition to the usual local mixing it includes a treatment of nonlocal mixing as a proportion of the surface layer heat and moisture fluxes is spread throughout the depth of unstable boundary layers.

The use of this scheme dramatically increased the amount of low cloud predicted in the Cheshire Gap case over the sea and land but reduced the amount of medium level cloud, see figure 14d compared with 14a. It also beneficially produced more convective precipitation over land, compare figures 13d and 13a, in association with the increased amount of cloud in the cloud band penetrating inland downwind from the North Channel, presumably due to more vertical mixing. Unfortunately the low cloud is then slightly too widespread and has a negative impact on the screen temperature forecast.

The impact on the Spiral Rainband case is to reduce further the amount of convection forecast over land, compare figure 15b and 15d. However the area of gridscale precipitation in the second band has spread further inland.

Inclusion of the modification to the boundary layer scheme in the stratocumulus case produced more low cloud over the sea and decreased the amount of shallow convective cloud, see figure 16 so that the areal coverage of low cloud is more like that from the OMMLAM forecast.

Both the boundary layer and convection schemes perform vertical mixing of heat and moisture. The use of the modified boundary layer scheme results in more boundary layer as opposed to convective mixing than with the original scheme.

4.9 Trial 2 and Operational version of New Mesoscale Model

In sections 4.7 and 4.8 the separate impacts of the modifications to the convection and boundary layer schemes were discussed. When both schemes were combined in the mesoscale version of the unified model along with the other changes from section 4.2 to 4.6 it was found that:

- the positive impact of the new convection scheme on the 23/8/91 case was greatly reduced in initial tests. However various corrections and ammendments have been made to the new convection scheme since the first tests were made. The impact of combining the final operational versions of the new boundary layer ,convection and gridscale evaporation schemes is shown in figure 15e compared with 15c where it can be seen that the inclusion of the new boundary layer scheme reduces the convection in Ireland and southern and eastern England. In the initial tests the combined schemes resulted in no convection over Ireland and only a small amount in southern England in the forward band at 12Z so that the results looked more like those with the modified boundary layer scheme only ie figure 15d.
- there was still a beneficial impact on the precipitation produced in the Cheshire Gap shower band, see figure 11e but still too much cloud cover, see figure 12f and reduced amount of medium cloud and convection to the north of Scotland.
- there was still extra beneficial low cloud over the sea in the 4/12/91 case.

This version increases the total cloud cover in the forecasts due to the shift in the balance between convective mixing (and hence small fractions of shallow convective cloud) and boundary layer mixing (and hence larger fractions of low cloud) towards boundary layer mixing.

In an attempt to find a configuration of the NMM that retained the benefits of the modified convection scheme on the 23/8/91 case and the modified boundary layer scheme on the 8/11/91 case, a further modification was made to the new convection scheme to increase the initial updraught mass flux still further by increasing the parameter C to $1\text{x}10^{-3}$ and to increase the parcel bouyancy excess used in tests for convective instability by increasing the potential temperature excess from 0.2 to 0.4°. This essentially means that the convection scheme will require less instability in the environmental profile for it to trigger and when it does the convection will be more vigorous. The isolated impact of this further change to the convection scheme on the Cheshire Gap shower band is shown in figure 13f and 14f. It can be seen that the distribution of convection over the sea is more broken and cellular and there is more predicted over land. This version is referred to as new convection and gridscale evaporation schemes with mesoscale convection parameters in the figures as it was adopted for Trial 2 and the initial operational version of the NMM.

The impact of this additional convection change when combined with the other modifications from sections 4.2 to 4.8 was to:

- Increase the amount of convective precipitation again (ie it was more widespread) in the 23/8/91 case, see figure 15f.
- Improve the cloud distribution over England and Wales in the Cheshire Gap case, see figure 12d, and still produce, but reduce, the amount of convective precipitation associated with the cloud band, see figure 13b. Make the structure of the convection over the sea be more cellular like the OMM and the cloud visible in satellite images on this occasion.
- make the convective and low cloud distribution in 4/12/91 case more similar to the basic unified model and trial 1 version, see figure 16c.

This version shifts the balance back towards convective mixing so that the cloud distribution is more similar to that in the basic model.

The version with the 'mesoscale' convection parameters was selected for the operational configuration of the NMM as for the cases investigated it appeared to give results closest to those of the observations and the old mesoscale model. It produced slightly more low cloud and precipitation in the 8/11/91 case without a detrimental effect on the screen temperature verification and generally better prediction of convection over land, particularly in the 23/8/91 case.

However there was little time available to test different configurations of the NMM properly if the deadline for operational implementation of the new model was to be met . The developments described in sections 4.2 to 4.9 were undertaken in parallel and only tested together for the first time in Trial 2. It was difficult to chose between the mesoscale and climate convection parameters and the decision was largely driven by the need to give good predictions of nighttime minimum temperatures. The use of the climate parameters gave excessive cloud overnight, particularly in the 8/11/91 case, which adversely affected the screen temperature forecasts. The impact of the slight overprediction of low cloud is exacerbated by the use of the random overlap assumption in the calculation of total cloud cover for the radiation schemes. When a more appropriate scheme for high vertical resolution can be used such as maximum random (ie maximum cover within a cloud, random overlap between different clouds) or maximum overlap the impact on the screen temperatures may be reduced.

From consideration of figure 15 it could be argued that the final version of the convection scheme with the climate/LAM parameters is producing adequate convection at 12Z 23/8/91 and the mesoscale parameters are producing too much. The forecasts compared in figure 15 were run without the inclusion of MOPS data. This was because, as can be seen from Figure 17c compared with figure 15b, the inclusion of MOPS data in the basic version of the NMM also has a positive benefit on the forward rainband, similar to the impact of the IMI on the OMM forecasts, see section 3 and figure 5. Figures 17a and 17b show the comparison of the full operational/trial 2 version of the NMM with the mesoscale and climate convection parameters. It can be seen that the general conclusions are still the same but the details of the precipitation fields are slightly different from those in figures 15f and 15e. In Figure 18 the 18 hour forecasts for 18Z 23/8/91 are compared. At this time the forecast with the climate convection parameters seems best and correctly forecasts a band of precipitation from south Wales to the Wash which was present in the OMMIMI forecast but absent in the basic NMM forecast and the trial 2 forecast.

From the trial cases it was seen that the evolution of precipitation bands is dependent on the convection parameters. This was also seen in an extra case, nominally a 30 hour forecast with data time 6Z 22/9/92 (run from 0Z 22/9/92 Global analysis with 6 hours data assimilation and boundary conditions from the 6Z 22/9/92 LAM assimilation and forecast). This was a period with exceptionally heavy rain overnight on 22/23 September in southern and eastern England as a result of a slow moving band of precipitation ahead of a disrupting upper trough. The forecasts were initially run without data assimilation (but still with 0Z global analysis and 6Z LAM boundary conditions) with the climate and mesoscale convection parameters. The run with the climate convection parameters correctly forecast the highest 6 hour rainfall accumulations in the period before midnight whereas the forecast with the mesoscale convection parameters forecast the highest accumulations to be after midnight. Once data assimilation was included the forecasts were poorer as the highest accumulations were forecast to be too far west and there was much less sensitivity in the evolution to the convection parameters.

8 to 10 cases are not really enough to discriminate between various versions of the model and operational experience may indicate that the climate/LAM convective parameters would give better overall results. In particular if it is found that overall the new model is producing too little cloud cover and/or too much convection an operational change to the climate/LAM values should be considered after further assessment.

5. Operational Trial in Winter 1992

5.1 Definition of Second Trial

A second performance trial (trial 2) of the new mesoscale model was run in winter 1992. This involved rerunning the 8 cases described in section 3 plus a few others, eg Frontal snow 6Z 17/2/92 and severe flooding 6Z 22/9/92 using the mesoscale version of the unified model including the modifications described in section 4. Appendix A contains a brief description of the model used in the winter 1992 trials. 31 levels were used for the case studies for direct comparison with the Spring 1992 trial (trial 1). Appendix B summarises differences between the operational LAM at the time of the trial and the new mesoscale model.

The results of the second trial and comparisons between the OMMIMI, here referred to as OMM, and NMMAC trial 1 and trial 2, here referred to as NMMTR1 and NMMTR2, performance are summarised below.

5.2 Data Assimilation.

Results are discussed in more detail in Macpherson et al 1993.

Inclusion of extra data by continuous assimilation leads to better retention of cloud and relocation of precipitation (latter to approx T+6 only) without problems of excessive convection at start of forecast found in OMM. In particular the assimilation of MOPS data had a significant positive benefit in relocating the band of thunderstorms in southern England at the start of the 6/7/91 forecast and was more successful than the IMI in the OMM. However the inclusion of the MOPS data, as with the IMI in the OMM, was unable to correct the evolution error in the forecast after about T+6.

The largest impact from MOPS was in the 4/12/91 stratocumulus case where the use of MOPS data correctly added low cloud over land at the start of the forecast and improved the prediction of cloud throughout the forecast period.

Use of extra surface data, screen temperatures, has a beneficial impact on production of fog in the 14/12/91 case, and temperatures, which can last through to the end of the forecast as in the positive impact on maximum temperatures for 1/9/91.

Not all impacts are beneficial such as the production of spurious fog in the 4/12/91 case and removal of stratus in the 1/9/91 case.

After the model was made operational an error was found in MOPS that resulted in level 1 relative humidities being forced towards 95% in cloud free areas rather than towards values less than 85%. This resulted in a moist bias in the NMMTR2 results and accounted for the spurious fog in the 4/12/91 case. This is discussed in Macpherson et al 1993.

5.3 10m Wind

Inclusion of the OMM roughness length scheme in the new model has resulted in 10m wind forecasts of comparable skill in the two models, eg rms speed errors, rms vector winds errors, mean and rms direction errors are now very similar, see figure 19 for comparison between OMM, NMMTR2 and NMMTR1. Mean wind speed errors are reduced by 2 - 3 knots throughout the day.

The positive impact of the change to the roughness lengths is isolated from other changes in figure 20 which shows the comparison between the mean and rms wind speed errors, rms vector wind errors and mean wind direction errors for the 5 0Z cases and 4 6Z cases used in trial 2. These results were calculated from forecasts rerun using corrected MOPS data. The impact on the rms vector wind error is greatest at night with a reduction in error of 1.5 - 2 knots overnight reducing to 0.75 - 1 knot during the day. The change to the physics between trial 1 and trial 2 also has an impact during the day resulting in a reduction of rms vector wind error of about 0.5 knots and reduces both the wind speed and direction errors. The inclusion of 10m wind data over land in the assimilation had negligable impact beyond T+0 , see Macpherson et al 1993.

Results for active cases 0Z 23/8/91 and 0Z 6/7/91 (and recent strong wind day 0Z 25/11/92) show a negative bias in daytime windspeed compared with observations and the OMM, see figure 21, which is reflected in the overall errors for the 0Z cases. This has been investigated for the trial cases and seems to be related to differences in evolution and location of cloud and precipitation in the two models. This can be seen by comparison of figure 21c, which shows the distribution of windspeed differences between OMM and NMMTR2 for 12 hour forecasts valid at 12Z 23/8/91, with figure 17a, which shows location of precipitation in forecasts for the same time. This also ties in with the impact of the new physics during the daytime. It is possible that the neglect of momentum fluxes in the non-local part of the new boundary layer scheme and the convection scheme is resulting in too little mixing of high velocity free atmosphere air towards the surface in unstable conditions.

Over the sea on occasions of strong winds the unified model 10m winds seem to be about 5knots lower than the OMM (and observations) .

Results from the trial show less backing of winds overland at night than reality and OMM, see figure 19c. However the exact direction predicted by the model overnight is probably not critical to the local forecasters as the local wind direction will be affected by topographic features that are not resolved by the model.

As found in the first trial the new model seems to have similar skill in sea breeze prediction to the OMM, see figure 22.

5.4 Screen Temperatures.

The increased resolution orography, plus use of screen temperature data, has led to more detail in temperature forecasts (much closer to that in the OMM). An example is the prediction of maximum temperatures in the hot day case, 1/9/91, see figure 23.

As can be seen by figure 24 the rms screen temperature errors have been reduced between trial 1 and trial 2 in the new model and are now lower than the OMM. The percentage correct within 2°C has also increased but there is an increased tendency for a negative temperature bias, particularly in the 0Z cases.

Macpherson et al 1993 shows that the use of screen temperature data, also to a smaller extent MOPS data, is responsible for the majority of the improvement in rms errors to T+9 in the 0Z forecasts but only 50% of the improvement for the rest of the forecast period. Figure 25 shows the impact on mean and rms errors and the percentage correct within 2°C of changes to the physics and roughness length. Assuming that the impacts are additive the change to the physics is responsible for most of the residual improvement in rms errors from T+9 onwards. For 4 6Z cases Macpherson et al 1993 also shows significant impact from the use of the screen temperature data to T+12, a maximim of 0.5°C in rms error at T+6 and T+9 reducing to a smaller impact of about 0.1°C for the rest of the period. From figure 25 we can see that the impact of the roughness and physics changes is typically only 0.1°C. These changes do not seem to account for the large difference between trial 1 and trial 2 beyond T+0 (the impact from the data, roughness and physics is very similar for the 3 6Z cases of trial 1 as for the 4 including 17/2/92). The largest differences are in the 14/12/91 and 11/12/91 cases. The latter has been rerun removing the roughness and physics changes, extra screen temperature and 10m wind data over land and MOPS data and reverting to 1/4hrly radiation calls and 10 boundary layer levels. This still does not reproduce the trial 1 results. The only remaining significant changes to the system between trial 1 and trial 2 were the use of hourly rather than 3 hourly surface data, solar angle update every time-step, use of orography and land- sea mask derived from 5' rather than 10' data and an error in the reconfiguration of the initial data for the 6Z runs in trial 1 which was corrected at trial 2. The error in the reconfiguration of the initial data for the 6Z forecasts in trial 1 resulted from the fact that a global analysis was used at T-6 which was directly reconfigured to the mesoscale grid. This meant that global orography was used in the boundary zone of 8 points rather than LAM orography so fields were inconsistent with the boundary conditions produced by the LAM forecast. In trial 2 the global analysis was correctly reconfigured to the LAM grid before final reconfiguration to the mesoscale grid.

Main errors in either model and differences between them are due to cloud errors. The error in the forecast screen temperatures in Scotland for 15Z 1/9/91 from the OMM, see figure 23, was due to the presence of too much cloud. The new model has a better prediction of frost on the 11/12/91 case (subzero day and night) as it does not have the erroneous cloud and fog present in the OMM, see figures 26 and 27. Unfortunately no marginal frost cases were run in the trial to really test the relative skills. Table 1 shows the higher skill of the new model compared with the old model for frost prediction in the 4 6Z forecasts. The new model has a worse temperature forecast on 6/7/91 case as it had too much cloud in Wales and the south of England, see figure 28.

5.5 Precipitation.

As shown in section 4 the new physics has improved the prediction of showers overland in the 8/11/91 and 23/8/91 cases so that NMMTR2 forecasts are now much closer to the OMM and observations than the NMMTR1, see figures 5, 11-15, 17 and 18. The precipitation forecasts from the LAM are also included in figures 5,11,17 and 18 and it can be seen that even when the new physics is included in the LAM there is more detail in the NMMTR2 forecasts.

The NMMTR2 tends to predict wider bands of precipitation, with more associated convection on edges, in contrast to the sharp rainbands in the OMM. In the 23/8/91 case this results in a slightly more realistic forecast from the NMMTR2 of the precipitation distribution.

It is difficult to correctly verify precipitation objectively however the objective skill scores for predicted precipitation rates compared with values derived from present weather reports is higher in the NMMTR2 than the OMM in the 00Z forecasts.

In tests of the new convection scheme in the LAM showers were predicted as snow in the summer with screen temperatures significantly above zero.This tendency for prediction of showers as snow rather than rain is hidden in operational forecasts by a modification of the chart package (showers are only shown as snow if the screen temperature T<2°C otherwise they are displayed as dynamic rain). Obviously further development of the convection scheme is required to remove this problem with the downdraught scheme. In the NMM trial cases the only case significantly affected by prediction of snow showers was the 8/11/91 case and here it was more marginal as wintry showers were reported at coastal stations but usually as hail rather than snow. Objective verification of the 8/11/91 case showed that although the NMMTR2 overpredicted snow showers , especially on the first day, it did have some skill overnight. The OMM, where showers are assigned as snow if the 1000' temperature is less than zero for verification purposes, also overpredicted snow during night but had less skill than new model .

Note that there is also a difference in output of convective precipitation in the two models as the OMM used a local rate (ppn/cloud cover) whereas the unified model outputs the gridscale rate. The use of a local rate may need to be considered for unified model for direct comparison with radar.

The extra case, 6Z 17/2/92, was added to investigate the relative skills of the OMM and NMM in predicting frontal snow and distinguishing the boundaries of rain and snow. A front moved eastwards into the Britsh Isles and became slow moving during the night of the 17th/18th and the precipitation turned increasingly wintry. Although Birmingham reported continuous moderate snow through the second half of the night, precipitation was more generally in the form of sleet. Although the OMM tended to produce slightly too much snow it provided more useful guidance than the NMMTR2 which was deficient in snow. From figure 29 it can be seen that at 6Z 18/2/92 the OMM has forecast a large area of snow corresponding well with the region of reported sleet and snow. The excessive snow forecast ahead of the front is due to a deficiency in the OMM precipitation scheme which had insufficient evaporation of snow. The NMMTR2 has underforecast the area of snow although the 20% snow probability line gives a slightly better indication of the southernmost extent. Maps of the screen temperature errors at 6Z 18/2/92 are also included in figure 29. It can be seen that the OMM screen temperatures are generally lower than the NMMTR2 which has a positive bias of up to greater than 2°C in the area where sleet and snow was observed whereas the errors in the OMM are much closer to zero. It is not clear whether this is the reason for the error in the phase of the precipitation or whether insufficient snow was produced aloft to depress the low level temperatures.

The severe flooding case 6Z 22/9/92, see section 4.9, was run to check that the new model can predict high rainfall accumulations, see figure 30. On this occasion the OMM correctly predicted high 6 hour accumulations in the periods before and after midnight, up to 40mm and 56mm respectively. This forecast compared reasonably well with maximum observed accumulations of 45mm and 28.8mm respectively and the band of high accumulations was approximately the correct width. Unfortunately the locations of the forecast maximum accumulations were slightly too far to the NW and the rainfall did not extend into SE and East Anglia. The NMMTR2 spread the rain slightly further east but the highest accumulations were still too far to the west and only reached a maximum of 7mm in the 6 hours before midnight. However maximum accumulations of 30-34mm in the period after midnight were reasonable and much better than the operational LAM which had maximums of 1mm before midnight and 7mm after midnight. The LAM with the new physics did slightly better with 5mm and 10mm respectively.

5.6 Cloud and fog

As mentioned in section 5.2 and Macpherson et al 1993 the modifications to the data assimilation scheme between trials 1 and 2 generally resulted in improvements to the short range prediction of cloud and fog compared with trial 1 and the OMM.

Objective verification shows that there is less cloud cover in the new model compared with the OMM and an overall negative bias but the rms cloud cover error is generally lower, see figure 31. The overprediction in the 6Z OMM forecasts is partly due to the overprediction of fog during the second night of the 14/12/91 case (fog cover is not distinguished from cloud cover in the model).

Away from analysis time both models produce similar numbers of forecasts in correct cloud base categories (0-1000', 1000-2000', 2000-5000', 5000-10000', 10000-20000' and 20000-40000') with the new model overpredicting amounts of cloud less than 1000' more frequently than the OMM and more frequently predicting bases too low rather than too high. The OMM predicted bases too high more frequently than too low during the first 18-21 hours of the forecasts. Over all cases the skill scores for cloud are generally higher in the new model than the old (cloud cover/base threshold categories) and rms errors in bases for cloud <8000' are lower in the new model than the old. For observed and forecast covers greater than 2.5 octas there is a tendency for bases to be too low in the new model but the biases are much closer to zero when the cover is greater than 4.5octas , see figure 32.

There is no clear signal as to which model has better cloud prediction, the performance is different and either model may be better in different situations. In active situations the errors in cloud cover are similar but with one or other of the models having more cloud at a given time.

The initial results from trial 2 showed very misleading fog prediction in the NMM with no or little fog being predicted when it was observed and spurious fog being predicted on other occasions when none was observed. However the spurious fog was due to the error in the preparation of the MOPS humidity data, see section 5.2 and Macpherson et al 1993, and once this was corrected this left the general characteristic of the NMM as being an underprediction of the occurance of fog. (Objective results using corrected MOPS data showed very little difference in the overall objective skill of cloud prediction and did not effect the relative skills of the NMMTR2 and OMM).

In the 4/12/91 stratocumulus case the new model retains cloud lost through initialisation problems in the OMM, see figures 6 and 16 and Macpherson et al 1993 but has a tendency for too much fog in cloud free areas which is improved with the correction to the MOPS data mentioned in section 5.2, see figure 33.

In the 8/9/91 case the OMM has too much med/high cloud in the south, probably due to a mismatch in saturation hmr between the IMI and model whereas the new model has a better forecast with a greater cloud free area, see figure 34. The original NMMTR2 forecast predicted spurious widespread fog overnight which was removed when corrected MOPS data was used.

The NMMTR2 underpredicted stratus and/or fog in the other anticyclonic cases 1/9/91 and 14/12/91 where stratus, fog, mist and/or shallow fog were observed whereas the OMM overpredicted their occurance , see figures 35 and 36. The OMM had better objective skill in fog prediction in the freezing fog case but overpredicted fog and low cloud in the second night. However the new model captured sea fog on a par with the OMM in the 6/7/91 case and an extra case, 6Z 22/5/92, although details of inland penetration were different.

There is still a tendency for the new model to predict shallow convective cloud in regions where the OMM has stratocumulus. A change to the convection parameters to the preferred climate model values will turn some of this to gridscale cloud (and make the model cheaper to run in cases where deep convection is unimportant). However there is a tendency for that version to overpredict low cloud and it needs further evaluation.

6. Conclusions

The developments to the unified model system between trials 1 and 2 of the new mesoscale model greatly improved the performance of the NMM relative to the observations and the OMM.

The trials showed the benefit of assimilating screen temperature data on the prediction of screen temperatures and visibility and the benefit of continuous assimilation of MOPS derived humidity profiles on the short period cloud and precipitation forecasts, see Macpherson et al 1993. The latter resulting in improved performance relative to the IMI in the OMM.

The trials showed the benefit of an enhanced surface roughness length scheme, taking into account the effects of subgridscale orography and features such as hedges and trees, on the prediction of 10m windspeeds and directions.

Improvements to the convection scheme to account for the effects of downdraughts improved the prediction of convective precipitation, especially over land. Further improvements, especially in the prediction of bands of convection in the NWrly airflows (the Cheshire Gap shower bands), resulted from a modification to the boundary layer scheme to allow for non-local mixing in unstable conditions.

Further benefits came from the use of orography derived from a higher resolution source dataset.

Relative to the LAM there were benefits from more frequent calls to the radiation schemes and the higher horizontal and vertical resolution.

Subjective and objective assessment showed that the overall skills of the OMM and NMMTR2 in predicting temperature, wind and precipitation are similar but they perform relatively better in different cases - ie the two models have different behaviour.

A short parallel trial of the new model was run in November/December 1992 and on the basis of the performance during that period and trial 2 described in section 5 the new model was accepted for operational implementation on 8th December 1992.

The new model will obviously behave in a much more similar manner to the LAM than the OMM as the former two models have the same basic formulation. Since the new physics available to the unified model system was introduced earlier in the mesoscale version than the LAM there were initially differences not just due to resolution. These were similar to differences between trial 1 and trial 2 of the mesoscale model. That is the wind speeds were lower in the mesoscale model than LAM and there was more convection over land. Figure 37 illustrates the impact of the new physics on differences between the NMM and LAM forecasts for forecasts for 6Z 1/3/93. The new physics (convection, boundary layer and grid-scale evaporation schemes) were introduced operationally in the LAM on 27/4/93 which will reduce the differences in the characteristics of the LAM and NMM forecasts. An enhanced roughness length scheme is not yet available for the LAM so it will still predict higher 10m windspeeds than the NMM.

Fog/visibility prediction in the new model needs more assessment and development. Therefore no routine output was produced for the outstation forecasters when the NMMTR2 was made operational. The error in the MOPS data was corrected operationally on 16th February. It is hoped that an improved version of the model can be introduced operationally in Autumn 1993.

The 4/12/91 case showed promising results for the prediction of stratocumulus in the new model. An assessment of the post operational performance of the new model in predicting and analysing stratocumulus is reported in Ballard and Macpherson 1993 which shows that further work is required to ensure that the operational performance becomes more reliable and always achieves the skill shown in this case study.

The new convection scheme has a positive benefit in that it increases the frequency of prediction of convection over land. However, as mentioned in section 5.5, it appears to predict the phase of the precipitation to be snow too frequently both over the sea and land when surface temperatures are much greater than 0°C. In some situations this can coincide with reports of hail showers. This is being investigated further but in the meantime the operational chart package has been altered to change the symbol to rain unless the surface temperature is less than 2°C.

The unified model melts falling snow to rain when the temperature of the layer it is falling through rises above 0°C. In the OMM snow was only allowed to start melting once the model layer wet bulb temperature rose above 0°C. This was implemented in the OMM as snow is frequently observed when temperatures are greater than 0°C at the surface and parametrises some extra microphysical processes. This has not been implemented in the mesoscale version of the unified model so its performance will be similar to the LAM and the snow probability lines will still need to be used to indicate liklihood of snow. The 17/2/92 trial case showed poorer performance in the new model compared with the OMM for prediction of precipitation phase however the 6Z 3/1/93 operational forecast from the new mesoscale model showed a good prediction of the phase of the frontal precipitation on that occasion, see figure 38.

A summary of the relative performances of the new mesoscale model compared with the OMM based on the pre-operational trials and early operational performance is given in Appendix C. Obviously this is based on only a few forecasts and forecasters should gain a better indication of the new model's skill from its daily use.

No assessment has been undertaken of the impact of the change in the dynamics, in particular the use of a hydrostatic rather than non-hydrostatic model. The main problems in the initial forecasts in trial 1 from the new mesoscale model were related to inadequacies in the surface characteristics, physics or data assimilation. The different formulation may explain some of the differences in the 10m wind forecasts and characteristics of the cloud and precipitation forecasts but this would require further investigation. It is planned that a non-hydrostatic version of the unified model will be developed in the next few years.

Obviously further development of the model is required and will be carried out in future. Work is underway to automate the MOPS cloud analysis, to include screen relative humidity data in the data assimilation scheme, to investigate the impact of extra near surface resolution (particularly on the prediction of fog), to develop an improved treatment of cloud phase and microphysics and to develop a more general treatment of the effects of orography in surface exchanges.

Although the mesoscale model is run at high resolution, so that sharper gradients and more detail can be predicted, the operational system (both OMM and NMM) does not yet have high resolution in all the surface forcing. Only the orography and surface roughness length are defined at the resolution of the model. As mentioned in section 2.4 and Appendix A the other fields defining vegetation and soil dependent surface characteristics, such as albedo, stomatal resistance, vegetation fraction, soil heat conductivity and thermal capacity are derived from 1° resolution data. The sea surface temperature (SST) is derived from an analysis at global(90km) model resolution. Additional benefits would be expected from the use of accurate high resolution surface fields, especially SST. A high resolution SST analysis system is being developed for use in the NMM. It is hoped that a project can be set up to provide higher resolution data for the other surface characteristics.

In the meantime, the developments reported here have brought the mesoscale version of the unified model up to a satisfactory standard for operational implementation which will make it easier to assess and enable further developments.

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Appendix A.
Mesoscale Unified Model Assimilation and Forecast System as used in Trial 2 and implemented operationally 8/12/92

Surface characteristics

Orography and land/sea mask derived from 5' data used for old mesoscale model. Domain is 92 x 92 with 0.15° resolution with pole 37.5N 177.5E, NW corner at 8.25N 352.95E rotated coordinates.

Other ancillary fields, including vegetative roughness length, derived from 1° unified model ancillary fields using 5' land/sea mask .

Extra roughness length field over land, z0orog, derived from old mesoscale model roughness length dataset and used to overwrite orographic roughness field in orography dataset. This gives Smith and Carson 1977 values for England, Wales and Scotland and 0.1m elsewhere. For non-mountainous areas this takes account of subgridscale effects of lakes, grass, fields, slopes, trees and buildings and for mountainous areas is a form of orographic roughness.

Model

The same basic version (2.7) of the unified model was used as for the LAM and global models operational at that time. However extra new physics developed for the climate model was also included ie: convective downdraught scheme (with values of parameters for convective mass flux and bouyancy increment as set in Vn2.7 code ie PARXS=0.4 and C=$1x10^{-3}$ rather than PARXS=0.2 and C=$5.17x10^{-4}$ as in the climate model), non local boundary layer scheme, new gridscale precipitation evaporation scheme consistent with new convection scheme.

31 levels with 27 wet levels and 13 maximum boundary layer levels were used with hourly updates in the radiation scheme (basic not ECMWF transmissivities ie as LAM not global model). Gravity wave drag and vertical diffusion were switched off. Second order horizontal diffusion was used for all variables with K=$4x10^4$ m^2s^{-1} (ie ∇^2). Divergence damping=$1x10^5$ in assimilation scheme, 4 point lateral boundary zone. Sigma coordinates to level 11, pressure above level 28. 90sec timestep. Relative humidity threshold for cloud = 0.925 for 1st 7 levels and 0.85 above.

Mesoscale model modifications from vn 2.7 release code were:

Correction to convective downdraught scheme (included in vn 2.8/3.0 code onwards)

Modified surface roughness scheme over land to be similar to current mesoscale model. z0m = min(z0orog,1.0) m, z0h = min(0.2*z0m, 0.1)m these are then both separately modified for the presence of snow as an extension of the current unified model scheme. The scheme is unmodified for other surface types including the sea.

Assimilation

Assimilation of screen temperature (including update of surface temperature) and 10m wind data overland and relative humidity profiles derived from MOPS as well as conventional unified model data. Hourly surface data (t-4 to t+1) and 3 hourly (t-3 and t+0) MOPS data. Modification from 2.7 code for inclusion of surface temperature update (included in vn 2.8 onwards). 6 hour assimilation period using data for t-3 and t+0.

Boundary and initial conditions

Boundary conditions from 20 level LAM assimilation and forecasts with same data time from t-6 to t+18/t+30 for 0Z and 6Z runs respectively. LAM run at vn 2.7 with basic physics. Starts from interpolated LAM analysis at t-6 for 0Z run and interpolated global analysis at t-6 for 6Z run.

NOTE: the operational version has 30 levels and runs off a 19 level LAM. There have been various operational changes since December 1992. Time-smoothing of the adjustment increments was introduced in January 1993 to reduce model instability causing forecast failures and to make NMM consistent with the LAM and global models. The calculation of MOPS relative humidities was corrected on 16 February 1993. Vn 3.1 is now operational and in April 1993 the LAM physics was updated to include the modified convection, boundary layer and gridscale precipitation evaporation schemes as used in the mesoscale and climate models.

APPENDIX B Differences between NMM, in trial 2 and initial operational version, and LAM until April 1993 when LAM convection, boundary layer and evaporation schemes were updated to those used in the NMM.

DIFFERENCES

LAM	New Mesoscale
49 km, 19 levels	16.8 km, 30 levels
229 x 132	92 x 92
5 min timestep	90 sec timestep
high order horizontal diffusion	2nd order horizontal diffusion
Assimilation of extra surface and humidity data in mesoscale version	
basic evaporation	new evaporation
basic boundary layer 5 levels	+ non-local mixing 13 levels
basic convection updraught only	downdraught convection
radiation every 3 hrs	radiation every hour
10' orography	5' orography
vegetative roughness	orographic roughness
0.008-0.016m (UK) up to 0.25m (Norway)	0.3-0.5m (lowland UK) 1m (mountains UK) 0.1m elsewhere

Appendix C.

Summary of performance of new mesoscale model relative to the old model

SCREEN TEMPERATURE

- rms errors lower
- errors/differences between models due to cloud errors/differences.

10m WIND

- rms speed errors approx same
- -ve speed bias in new model during day in certain conditions
- lower speeds in high wind situations
- lower speeds over sea
- direction more veered at night, less lee troughing

PRECIPITATION

- poorer frontal rain/snow distinction
- more widespread, wider bands, more widespread convection
- lower accumulations in extreme situations eg 22-23/9/92, 30/12/92
- too many snow showers (but changed to rain on charts if T>2°C)

CLOUD

- new assimilation of cloud produces better retention of cloud than IMI
- rms cover errors lower
- less cloud, -ve bias in cover
- mean and rms low cloud (<8000') height errors lower
- tendency for -ve height bias for >2.5 octas cover, closer to zero for >4.5 octas cover

FOG

- Not part of acceptance criteria for model and needs further assessment
- lower skill than current model - eg too little when foggy (after MOPS corrected)

SCREEN TEMPERATURE									--------FROST--------					
H	FC	<1	<2	<3	<4	<5	MEAN	RMS	OBS	FC	HR	FAR	SS	N
6	0	93	97	99	99	99	0.0	0.8	35.1	36.2	97	6	93	621
9	3	51	82	94	98	100	-0.1	1.6	30.8	3C.8	89	11	84	698
12	6	46	78	94	98	100	0.7	1.7	16.9	8.5	40	21	37	658
15	9	48	79	92	97	99	0.7	1.7	14.3	6.3	32	29	29	663
18	12	37	69	87	94	98	0.0	2.1	21.8	21.6	68	32	59	638
21	15	37	64	80	90	94	-0.1	2.4	24.9	28.2	75	34	62	610
0	18	36	62	78	87	93	-0.1	2.7	25.8	29.5	75	35	61	550
3	21	39	59	74	86	93	0.0	2.7	26.2	31.1	73	38	57	470
6	24	38	60	77	86	92	0.0	2.7	23.1	26.5	70	39	57	597
9	27	39	64	78	87	93	0.1	2.5	20.6	21.6	63	40	52	684
12	30	48	74	86	94	97	0.5	2.0	9.3	4.4	38	21	37	653

a)

SCREEN TEMPERATURE									--------FROST--------					
H	FC	<1	<2	<3	<4	<5	MEAN	RMS	OBS	FC	HR	FAR	SS	N
3	3	39	67	82	92	97	-1.3	2.3	29.9	42.6	94	34	74	578
6	6	38	66	83	93	97	-1.1	2.2	35.1	45.1	95	26	78	621
9	9	50	78	90	95	99	-0.7	1.8	30.8	34.2	92	17	84	698
12	12	57	84	95	98	99	0.1	1.5	16.9	11.2	58	14	56	658
15	15	57	82	92	97	99	0.4	1.6	14.3	4.4	24	21	23	663
18	18	50	79	95	98	99	-0.2	1.6	21.8	24.3	88	21	81	638
21	21	48	80	92	97	99	-0.3	1.7	24.9	29.0	88	25	78	610
0	24	46	75	90	96	99	-0.2	1.8	25.8	27.6	83	22	75	550
3	27	45	76	91	97	99	-0.1	1.8	26.2	29.4	87	22	78	470
6	30	48	76	90	97	99	0.1	1.8	23.1	23.5	75	26	68	597
9	33	50	81	93	97	98	0.4	1.7	20.6	17.3	70	17	66	684
12	36	54	80	91	96	98	0.4	1.8	9.3	6.6	64	9	63	653

b)

Table 1 Screen temperature verification for OMM and NMMTR2 calculated for 6Z runs on 8/11/91, 11/12/91, 14/12/91 and 17/2/92 to show better scores for frost prediction in NMMTR2 for these cases.
a) OMM.
b) NMMTR2.
Columns are:-
H = time of day
FC = hour into forecast
<1, <2, <3, <4, <5 = percentage of forecast temperatures within 1,2,3,4,5°C of observed values
mean and rms errors
% of observations with frost.
% of forecasts with frost.
HR = hit rate, FAR = false alarm rate, SS = skill score.
N= total number of observations included in the statistics.

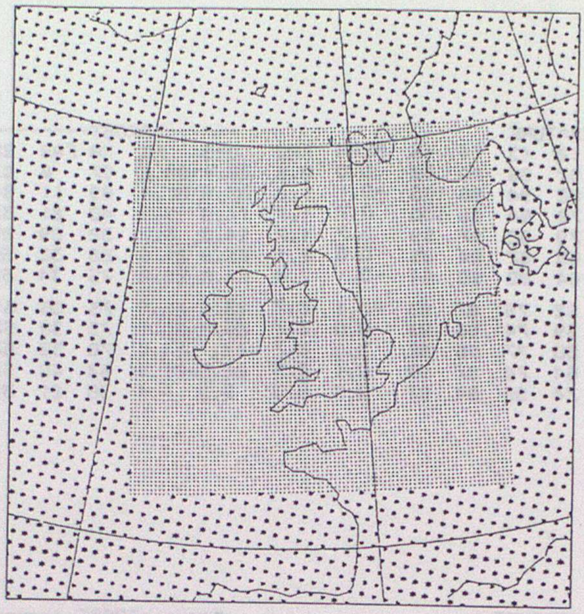


FIGURE 1. New mesoscale model domain and gridpoints shown within part of the LAM grid.

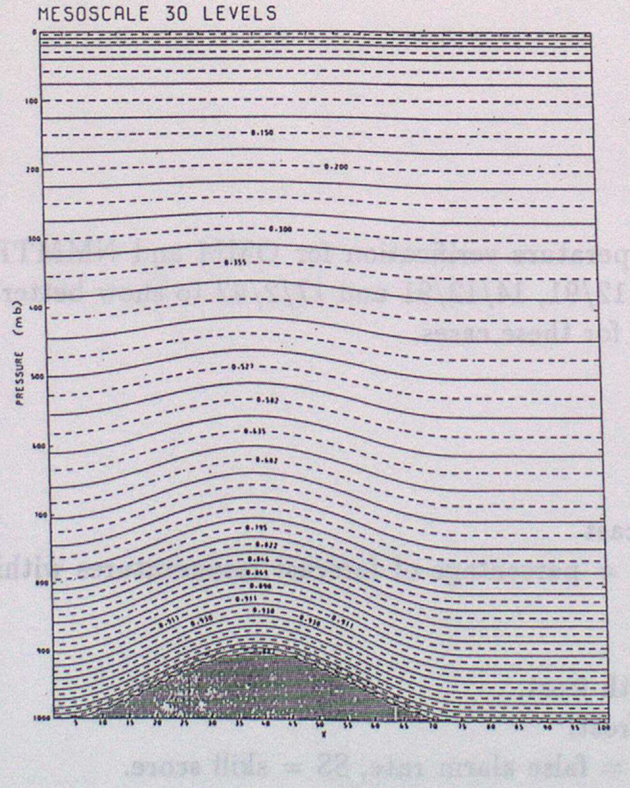


FIGURE 2. Full (—-) and half-levels (- -) of the operational NMM.

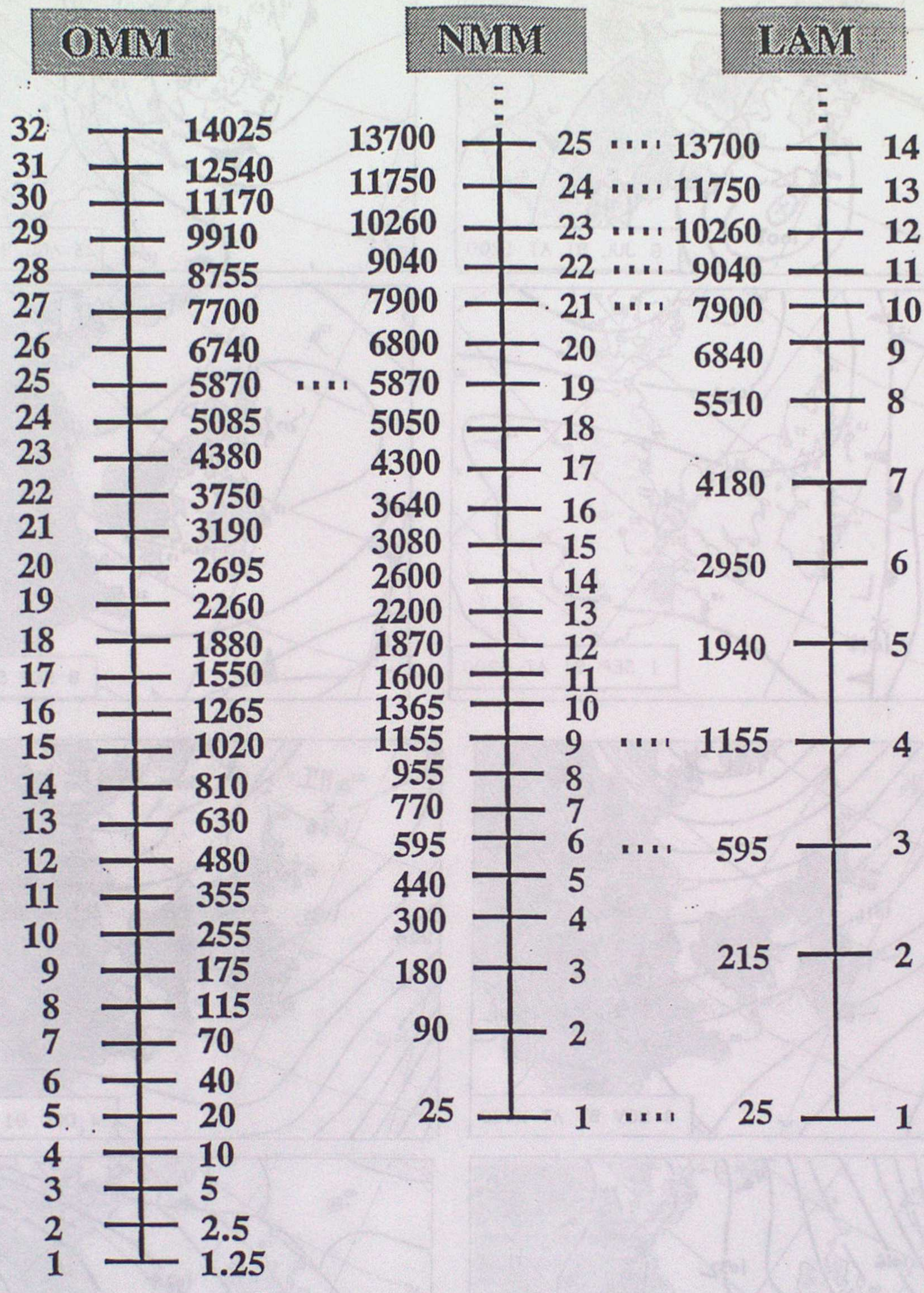


FIGURE 3. Comparison of model level heights in old mesoscale (OMM), new mesoscale (NMM) and Limited Area (LAM) models. Heights are in metres. All levels are shown for OMM but only the tropospheric levels are shown for the NMM and LAM. Heights for the NMM and LAM are approximate.

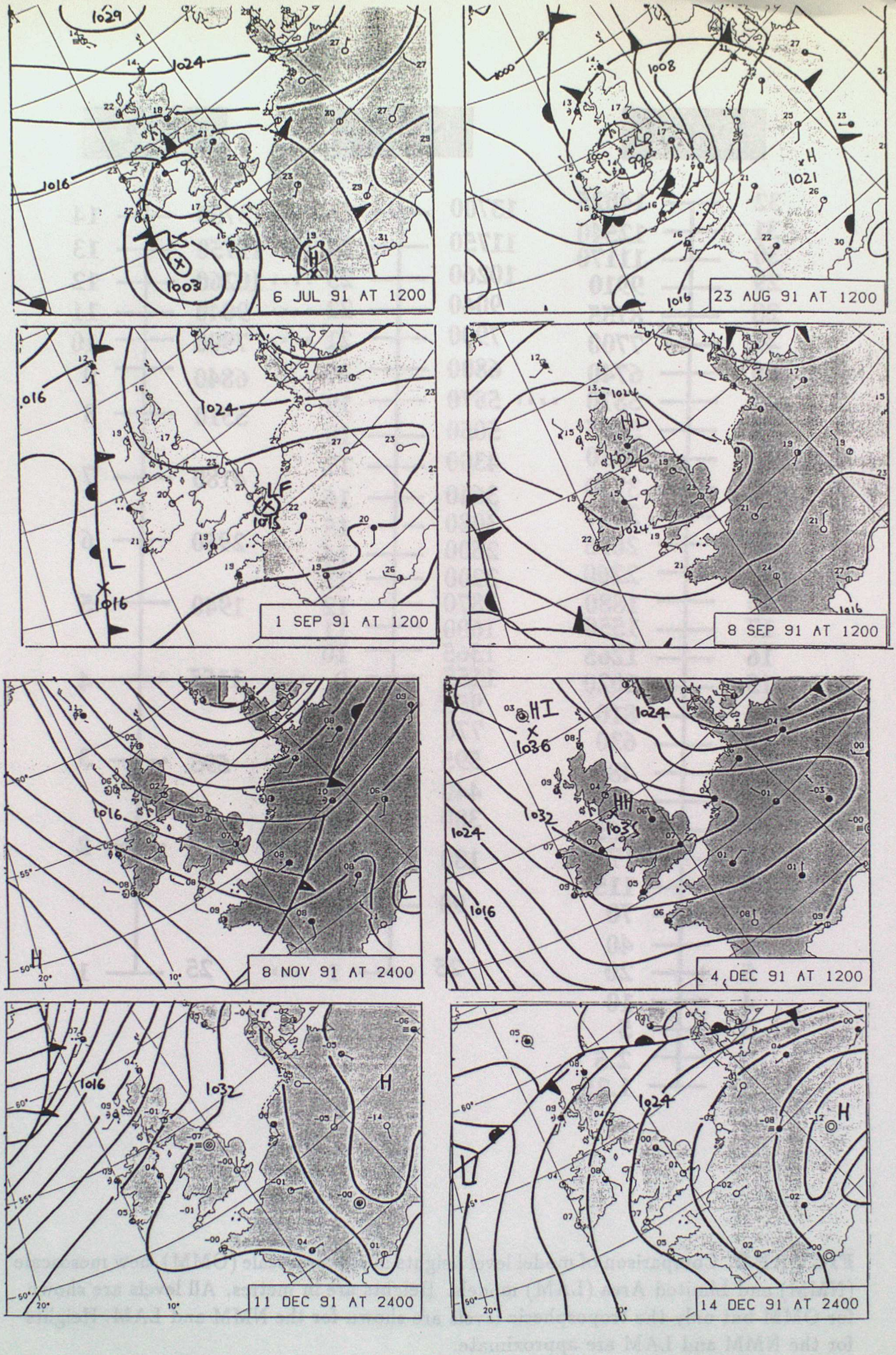


FIGURE 4. Synoptic situation for mesoscale pre-operational trial cases. Maps show mean sea level pressure, surface fronts and selected surface observations.

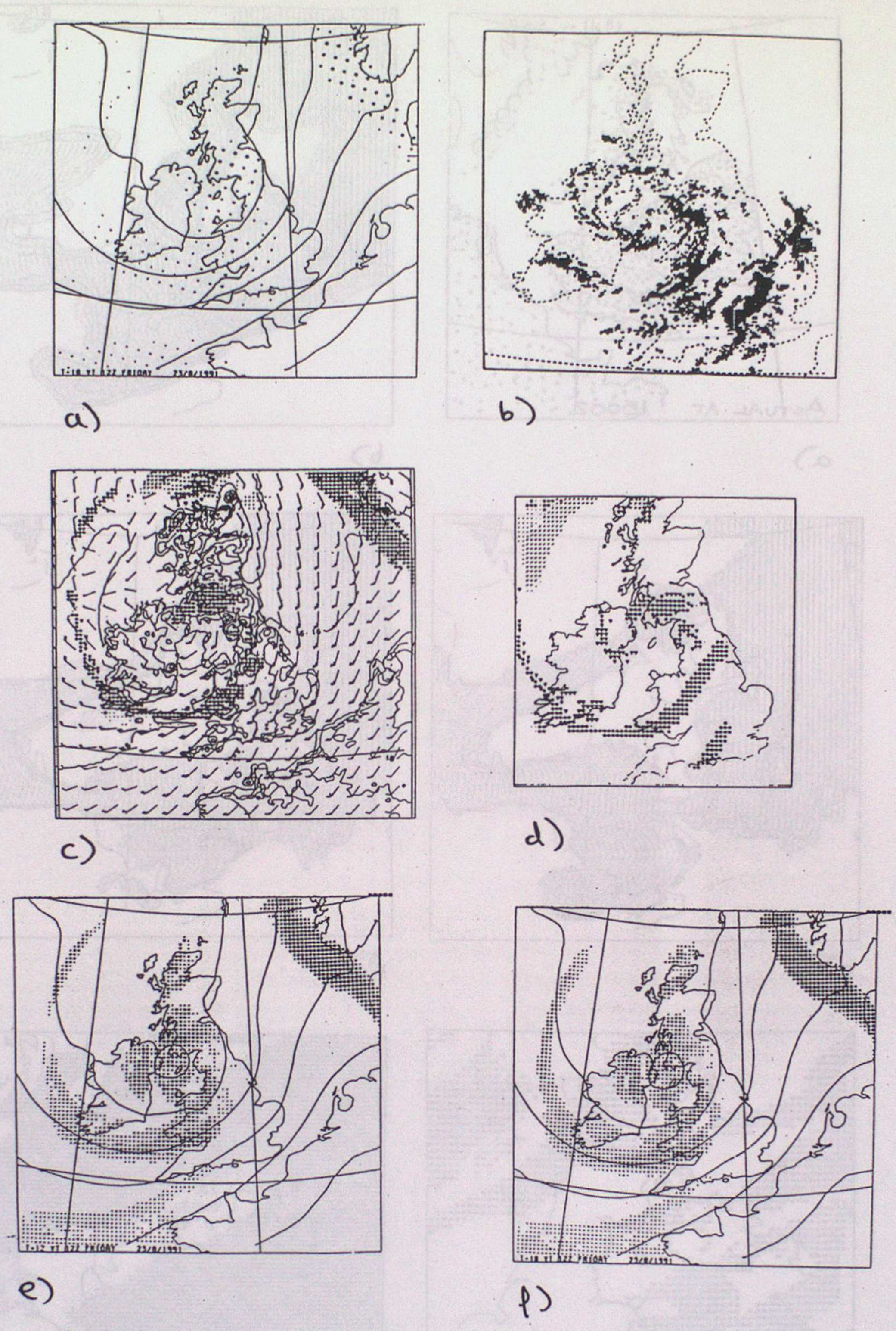


FIGURE 5. Comparison of observed and forecast surface precipitation rates at 12Z 23/8/91.

a) 12 hour forecast from LAM vn 2.4. Contours show pmsl, dots show location of forecast precipitation greater than 0.03mm/hour, circles are greater than 0.1mm/hr.

b) FRONTIERS radar observed rain rates. Black areas have rates greater than 0.125mm/hour. No coverage in Scotland.

c) 12 hour OMMLAM forecast. Arrows are 10m wind, contours are screen temperature, dots show location of forecast precipitation greater than 0.05mm/hour, circles are greater than 0.1mm/hr, triangles show local convective rates greater than 0.4mm/hr.

d) 12 hour OMMIMI forecast. Precipitation as c). Fs and dashes mark locations of fog and low visibility.

e) 12 hour NMMLAM forecast. Symbols as a).

f) 12 hour NMMAC forecast. Symbols as a).

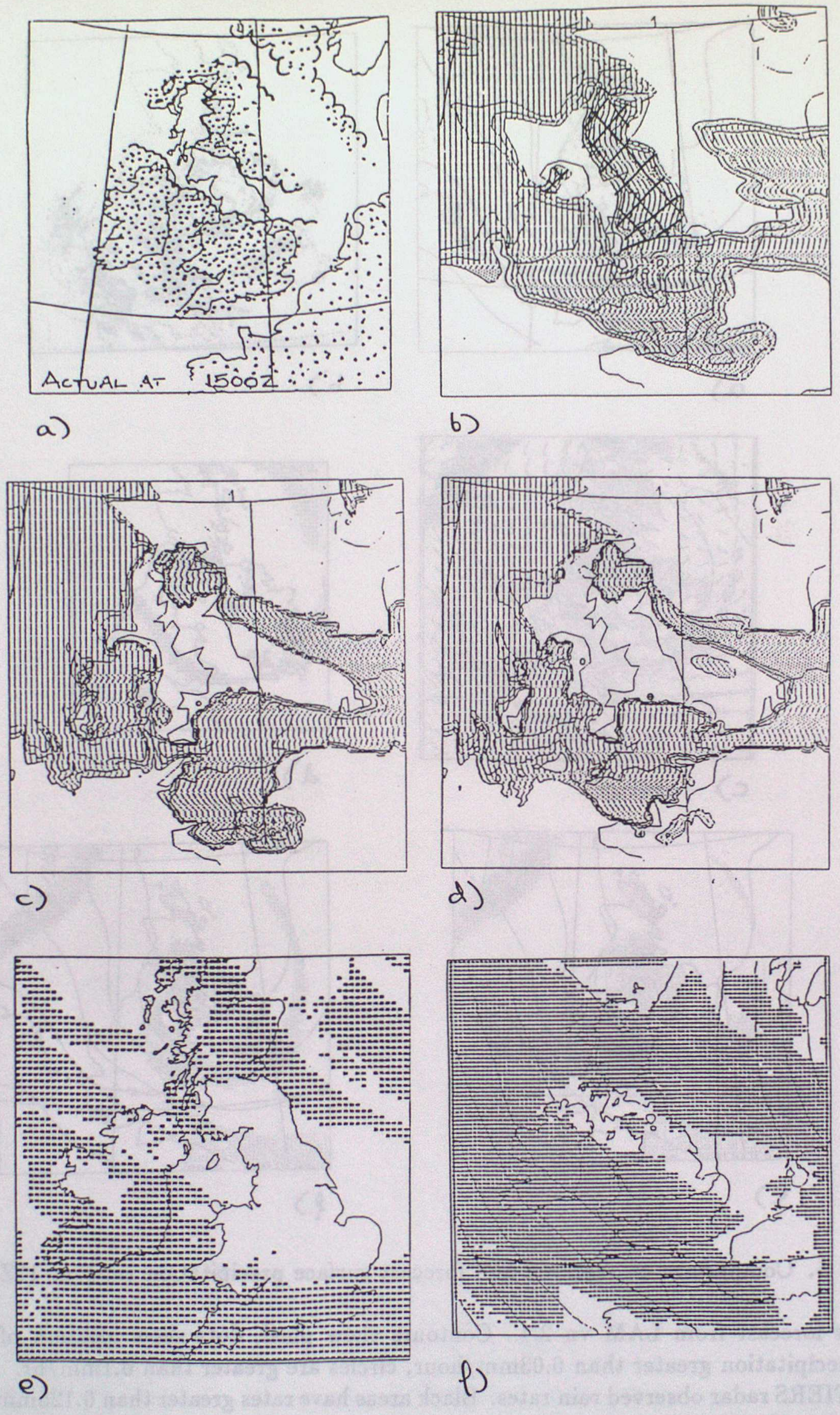


FIGURE 6. Comparison of observed and forecast total cloud cover at 15Z 4/12/91. The edge of areas with greater than 3 oktas cover is defined in the observations and areas with greater than 3 oktas cover are shaded in the forecasts.

a) observed cloud edge

b) LAM 15 hour forecast, version 2.4. Hashed area marks cloud at level 1 only, ie fog

c) NMMAC 15 hour forecast, trial 1 version

d) NMMLAM 15 hour forecast, trial 1 version

e) operational OMM 15 hour forecast

f) OMMLAM 15 hour forecast

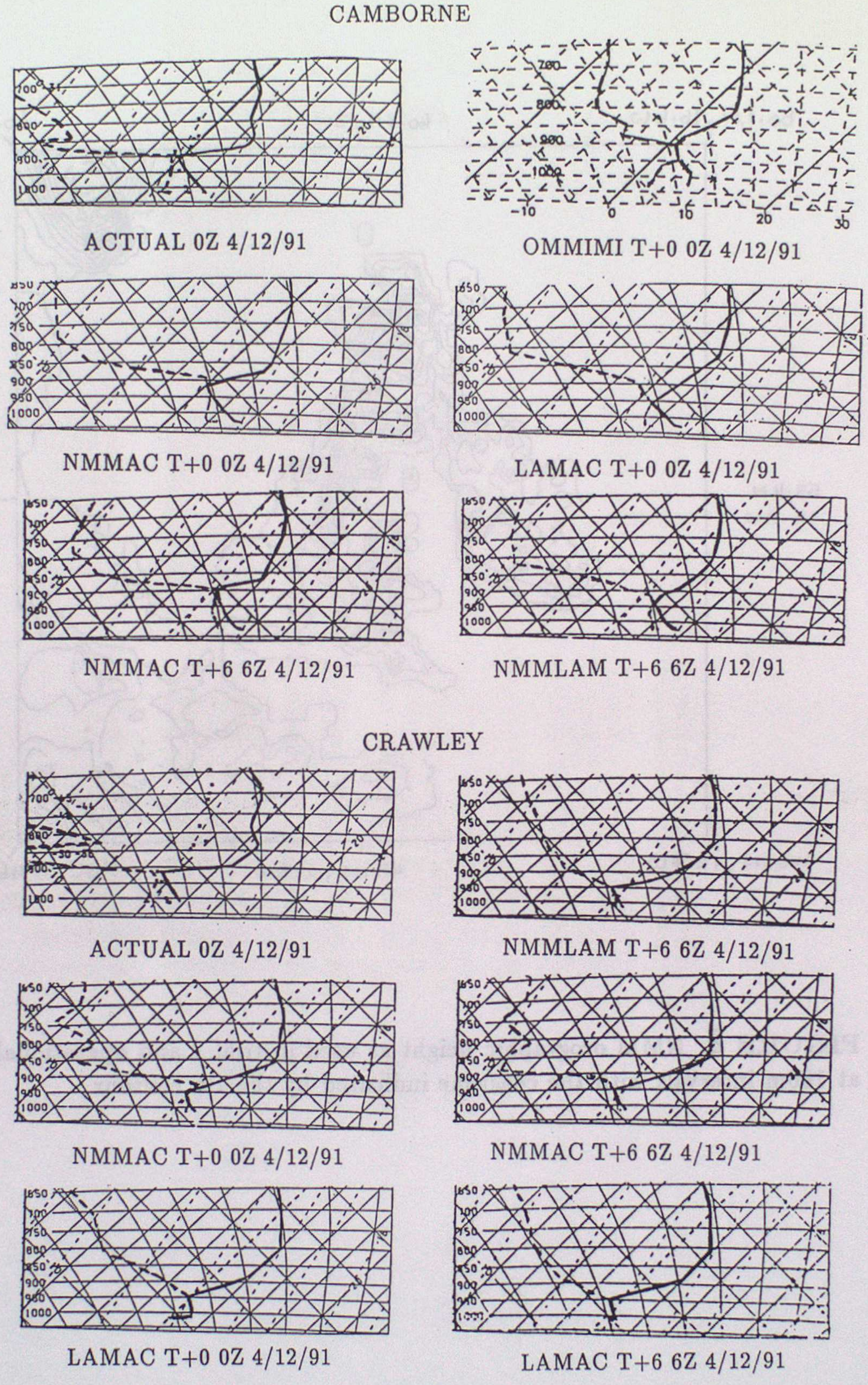


FIGURE 7. Comparison of actual and Trial 1 forecast Camborne and Crawley ascents for 4/12/91 case showing positive impact from assimilating radiosonde data at high vertical resolution in NMMAC which has best definition of cloud top and dry air above inversion.

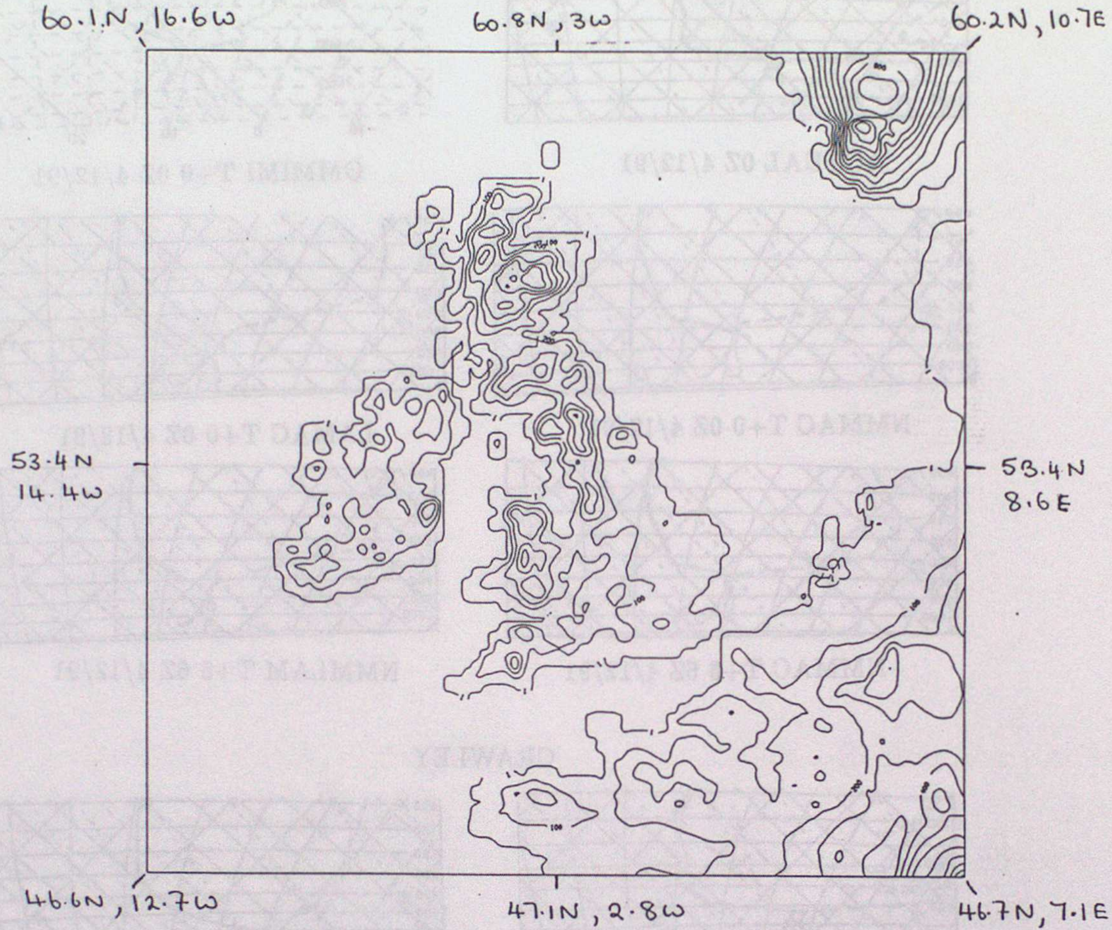


FIGURE 8. NMM orographic height as used in trial 2 and operationally. Contours at 100m intervals with the coastline indicated by the 1m contour.

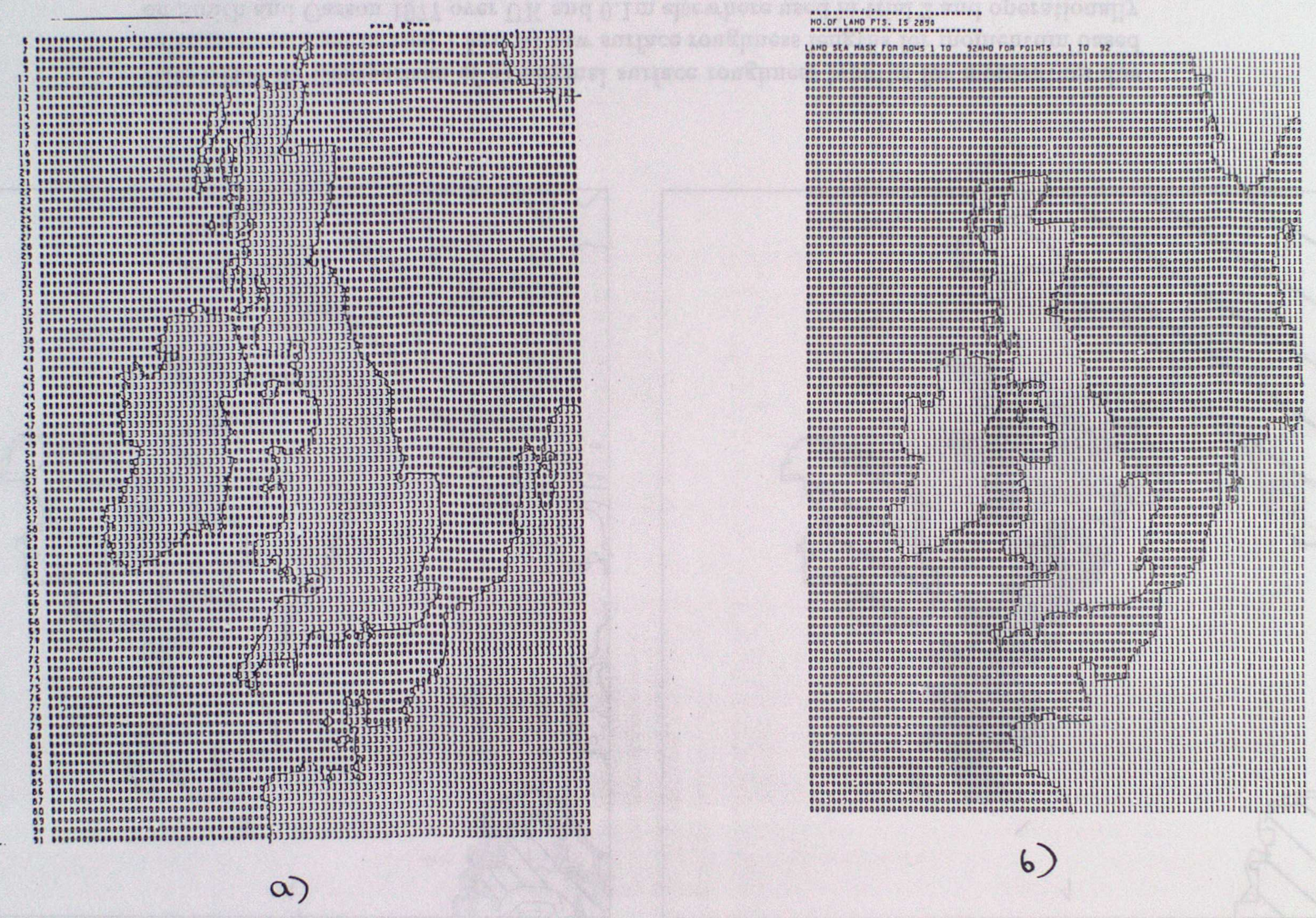


FIGURE 9. Comparison of OMM and NMM (trial 2 and operational) land sea masks. Sea points are indicated by zeroes and land points by values greater than zero. a) OMM, b) NMM.

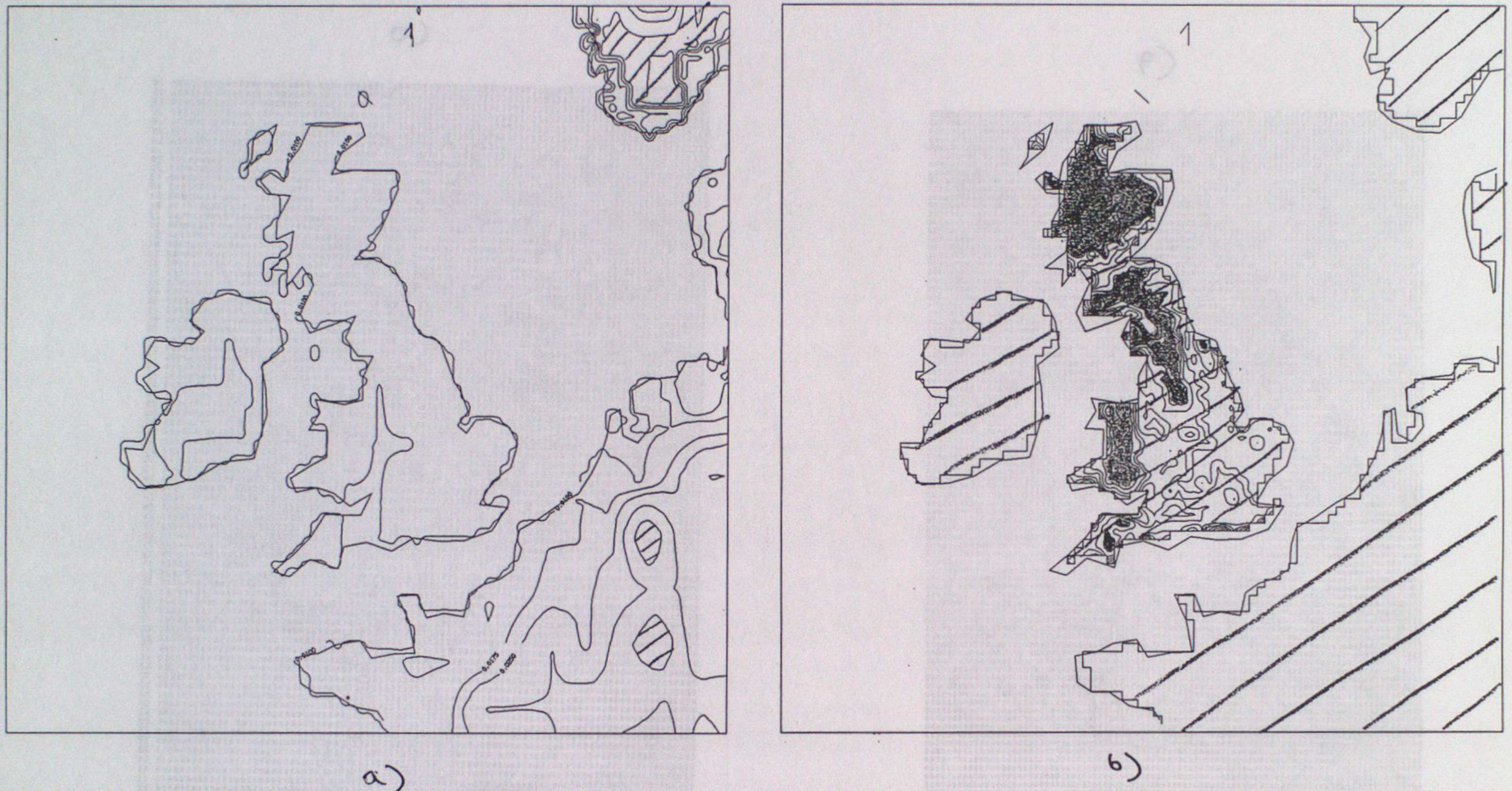


FIGURE 10. Comparison of a) original surface roughness lengths for momentum due to vegetation used in trial 1 and b) new surface roughness lengths for momentum based on Smith and Carson 1977 over UK and 0.1m elsewhere used in trial 2 and operationally in mesoscale model. Contours at 0.01, 0.0175, 0.025, 0.05, 0.1, 0.2, 0.5, 1.0, 2.5, 5.0, 10.0, 20.0m intervals. Values at or above 0.1m hashed and above 1m shaded.

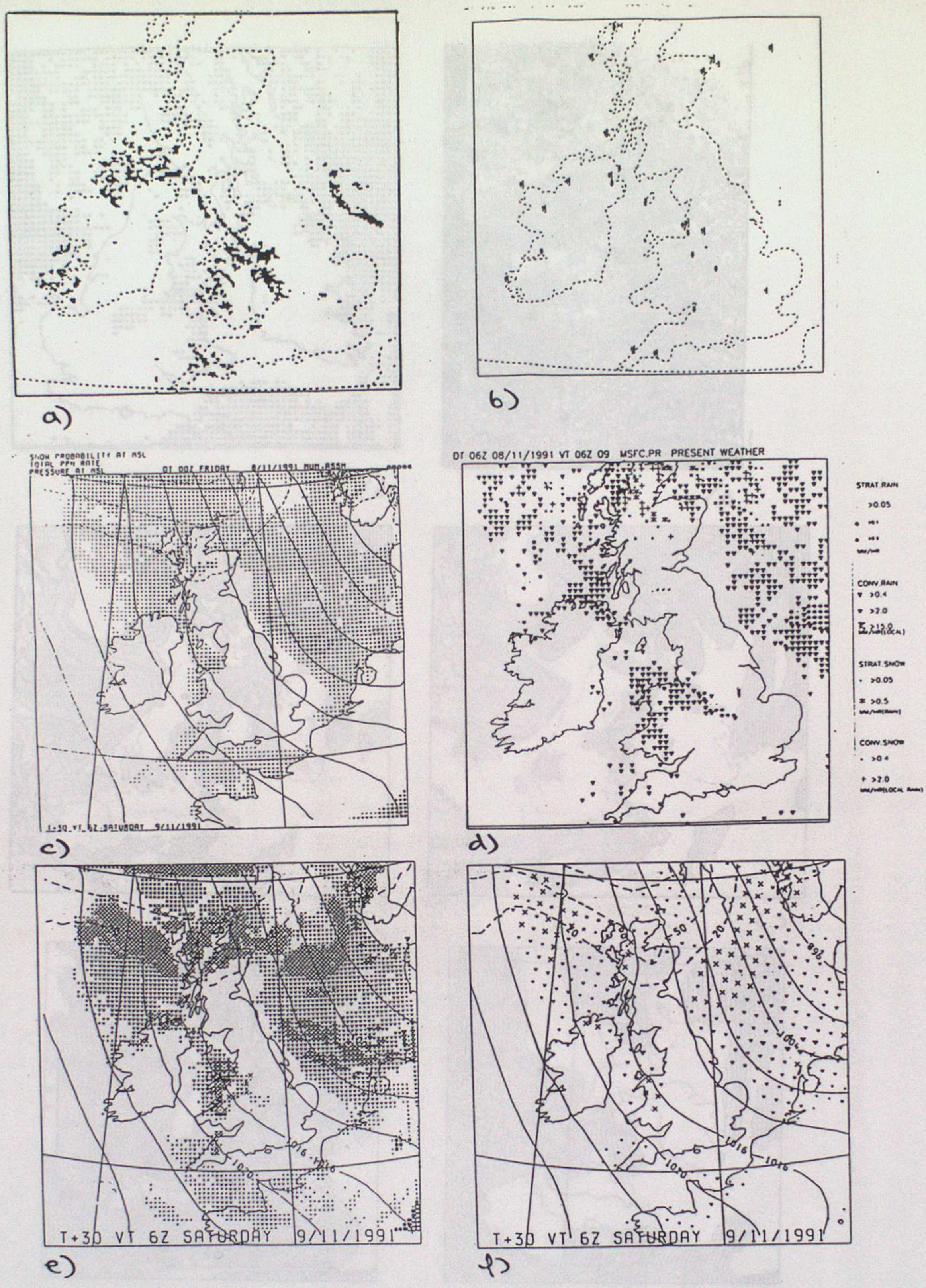
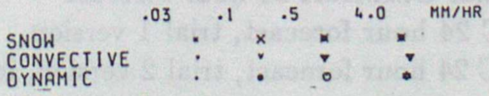


FIGURE 11. Comparison of observed and forecast surface precipitation rates at 6Z 9/11/91.

a) FRONTIERS radar observed rain rates. Black areas have rates greater than 0.125mm/hour. No coverage in Scotland.

b) Surface observations of present weather showing locations of current and recent showers and precipitation. c) 24 hour forecast from NMMAC trial 1. Contours show pmsl. Symbol table is as shown below.



d) 24 hour OMMIMI forecast. Symbol table is as shown

e) 24 hour forecast from NMMAC trial 2 but with climate/LAM convection parameters, ie vn 2.7 with changes from section 4. Symbols as c).

f) 24 hour forecast from LAM vn 2.7 with new convection, boundary layer and gridscale evaporation schemes. Symbols as c).

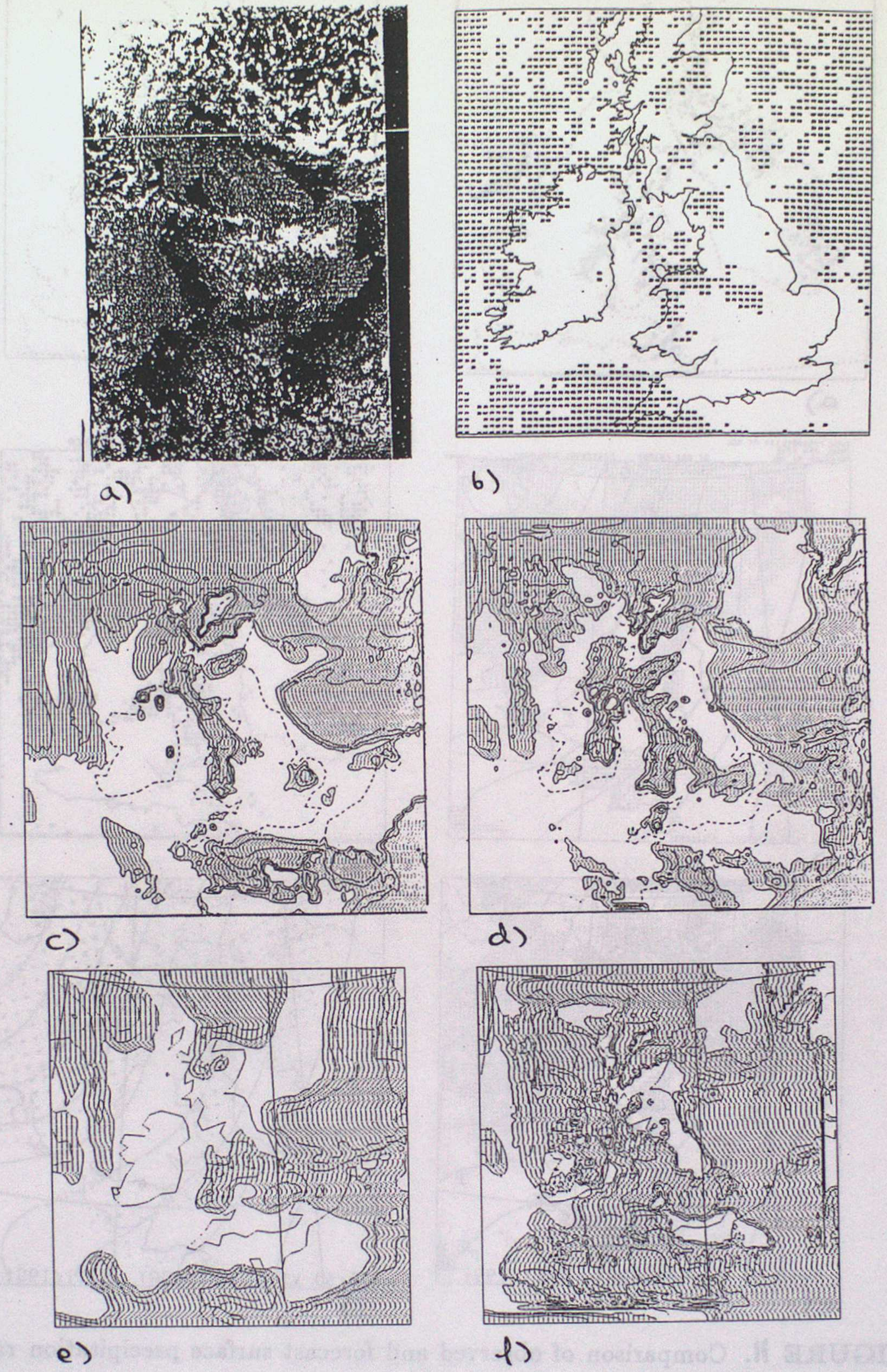


FIGURE 12. Comparison of observed and forecast total cloud cover at 6Z 9/11/91. Areas with greater than 3 oktas cover are shaded in the forecasts.
a) observed cloud cover from 0430Z AVHRR infra-red image.
b) operational OMMIMI 24 hour forecast
c) NMMAC 24 hour forecast, trial 1 version
d) NMMAC 24 hour forecast, trial 2 version, ie vn 2.7 with changes from section 4 and mesoscale convection parameters.
e) LAM 24 hour forecast, vn 2.7 with new convection, boundary layer and gridscale evaporation schemes.
f) NMMAC 24 hour forecast, trial 2 version, ie vn 2.7 with changes from section 4, and climate/LAM convection parameters.

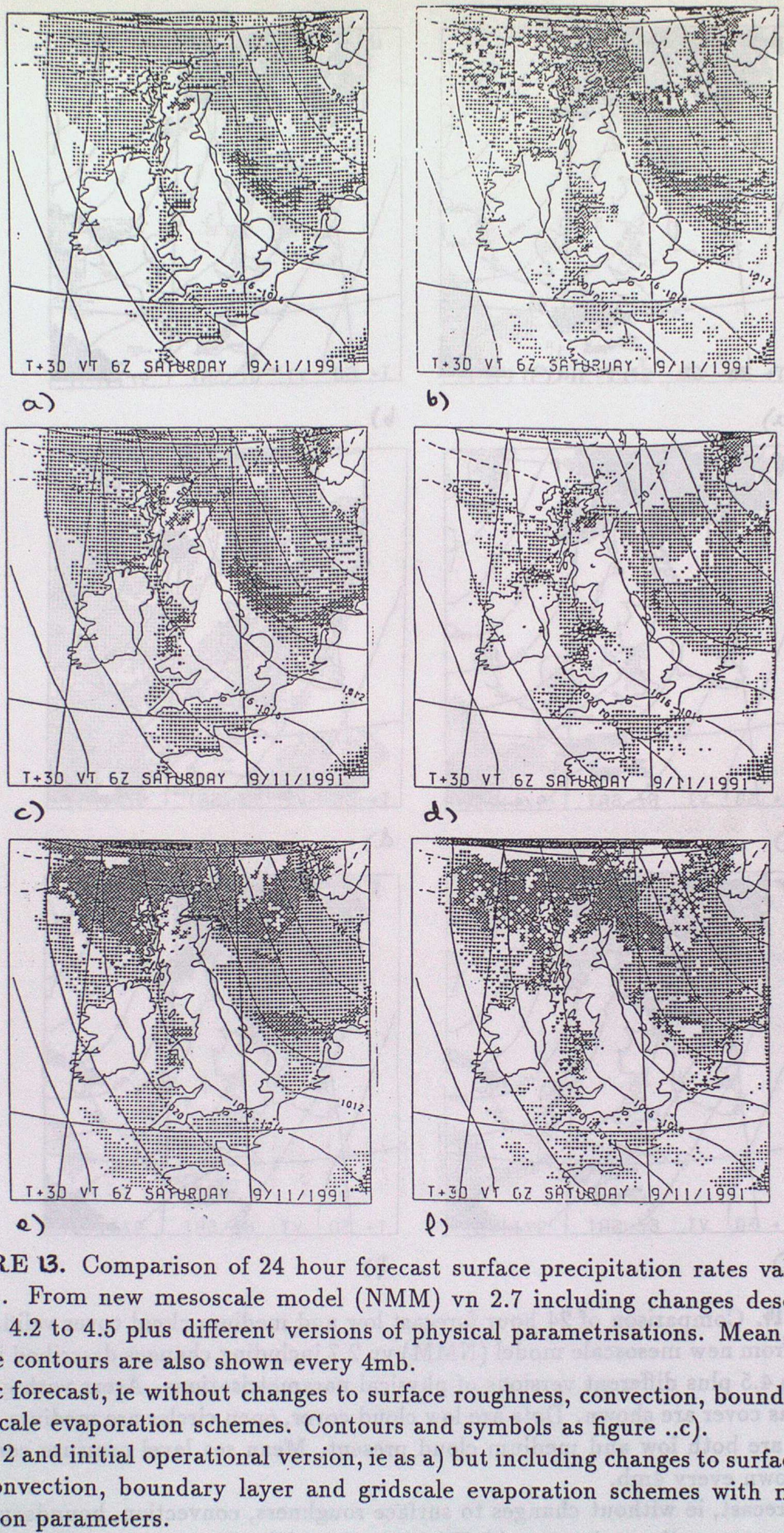


FIGURE 13. Comparison of 24 hour forecast surface precipitation rates valid at 6Z 9/11/91. From new mesoscale model (NMM) vn 2.7 including changes described in sections 4.2 to 4.5 plus different versions of physical parametrisations. Mean sea level pressure contours are also shown every 4mb.

a) Basic forecast, ie without changes to surface roughness, convection, boundary layer or gridscale evaporation schemes. Contours and symbols as figure ..c).

b) Trial 2 and initial operational version, ie as a) but including changes to surface roughness, convection, boundary layer and gridscale evaporation schemes with mesoscale convection parameters.

c) As a) but including new surface roughness scheme.

d) As a) but including new boundary layer scheme.

e) As a) but including new convection scheme and gridscale evaporation scheme with climate/LAM convection parameters.

f) As a) but including new convection scheme and gridscale evaporation scheme with mesoscale convection parameters.

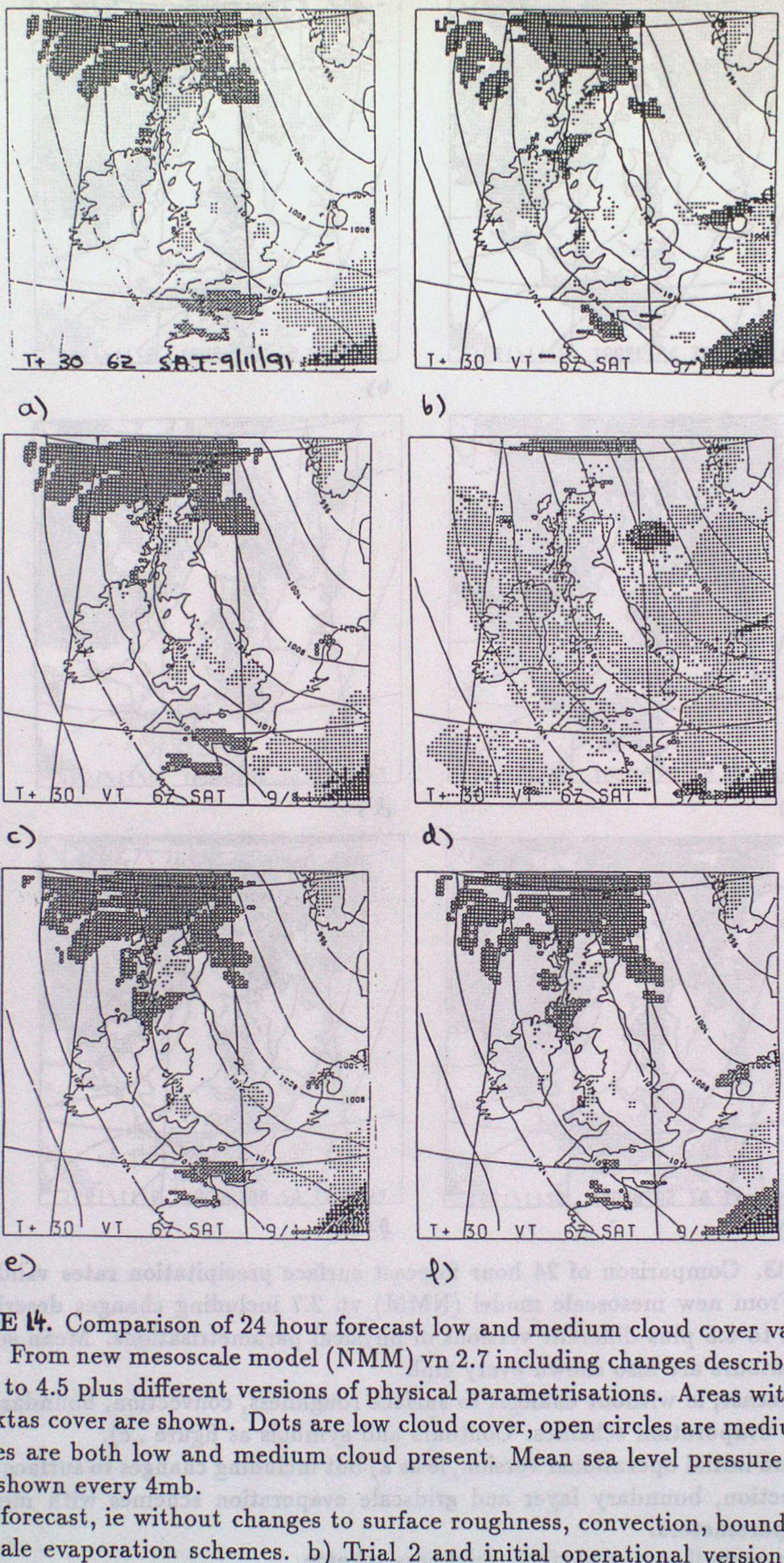


FIGURE 14. Comparison of 24 hour forecast low and medium cloud cover valid at 6Z 9/11/91. From new mesoscale model (NMM) vn 2.7 including changes described in sections 4.2 to 4.5 plus different versions of physical parametrisations. Areas with greater than 4 oktas cover are shown. Dots are low cloud cover, open circles are medium cover, full circles are both low and medium cloud present. Mean sea level pressure contours are also shown every 4mb.

a) Basic forecast, ie without changes to surface roughness, convection, boundary layer or gridscale evaporation schemes. b) Trial 2 and initial operational version, ie as a) but including changes to surface roughness, convection, boundary layer and gridscale evaporation schemes with mesoscale convection parameters. c) As a) but including new surface roughness scheme. d) As a) but including new boundary layer scheme. e) As a) but including new convection scheme and gridscale evaporation scheme with climate/LAM convection parameters. f) As a) but including new convection scheme and gridscale evaporation scheme with mesoscale convection parameters.

FIGURE 15. Comparison of observed and 12 hour forecast surface precipitation rates valid at 12Z 23/8/91. From new mesoscale model (NMM) vn 2.7 including changes described in sections 4.2 to 4.5, except MOPS data, plus different versions of physical parametrisations. Mean sea level pressure contours are also shown every 4mb.

a) FRONTIERS radar observed rain rates as Figure 5b).

b) Basic forecast, ie without changes to surface roughness, convection, boundary layer or gridscale evaporation schemes. Contours and symbols as figure ..c).

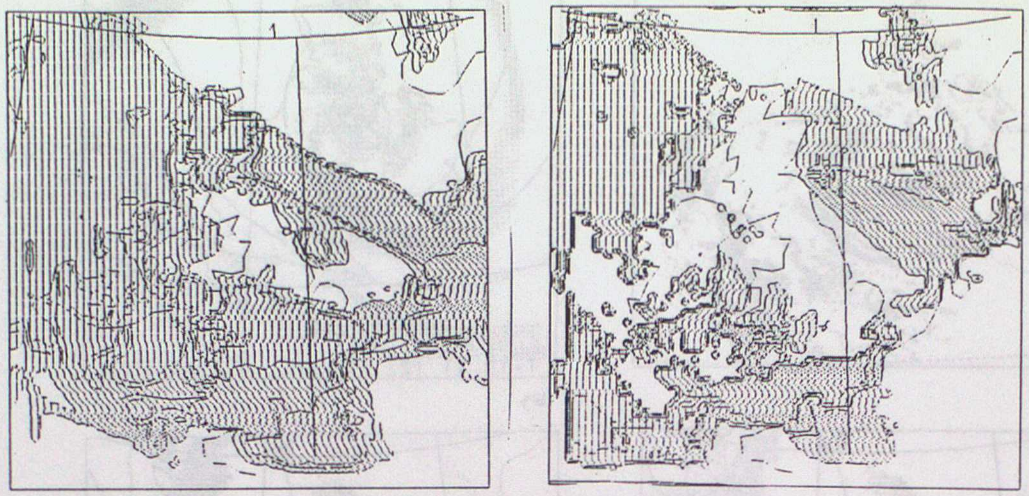
c) As b) but including new convection scheme and gridscale evaporation scheme with climate/LAM convection parameters.

d) As b) but including new boundary layer scheme.

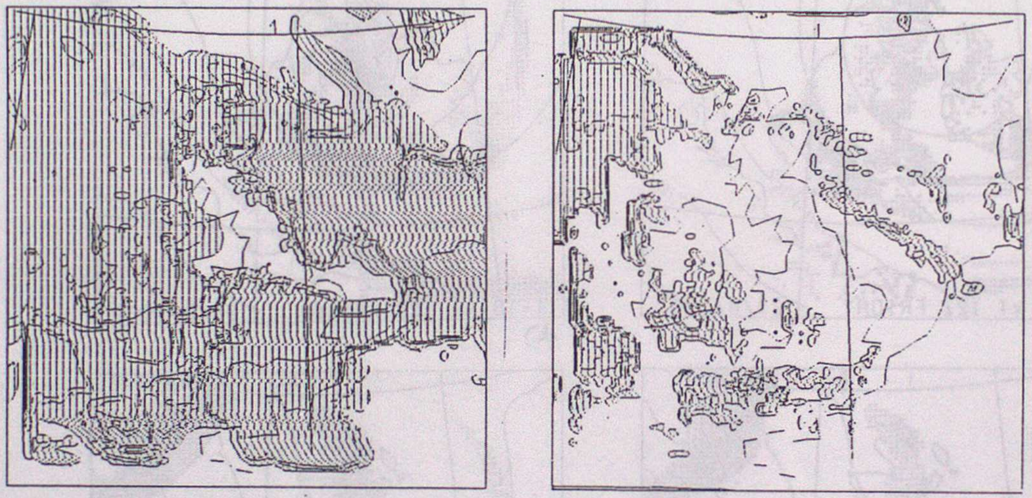
e) As c) but also including new boundary layer scheme.

f) As e) but with mesoscale convection parameters.

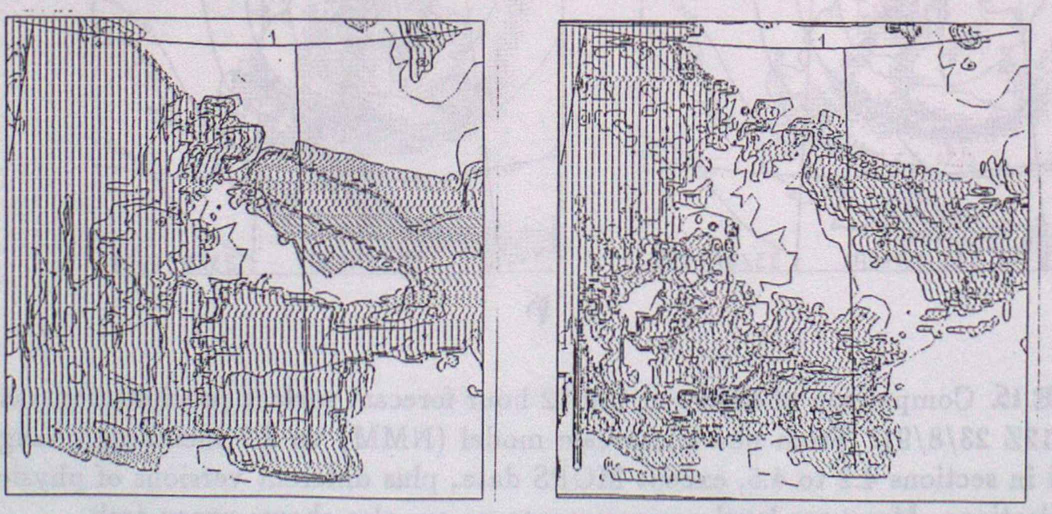
low cloud cover | convective cloud cover



a) NMM trial 2 but with basic physics ie boundary layer, convection, gridscale precipitation and roughness length as trial 1.



b) as a) but with non-local boundary layer scheme included.



c) NMM trial 2, ie as a) but with modification to boundary layer, convection, gridscale precipitation and roughness length included.

FIGURE 16 Comparison of 15 hour forecasts of low and convective cloud cover verifying at 15Z 4/12/91. Areas with low cover greater than 3 oktas are shaded and contour intervals at 3,5,7 and 9 oktas. Areas with convective cloud cover greater than 0.3 oktas are shaded with contour intervals 0.3,1,1.5 and 9 oktas.

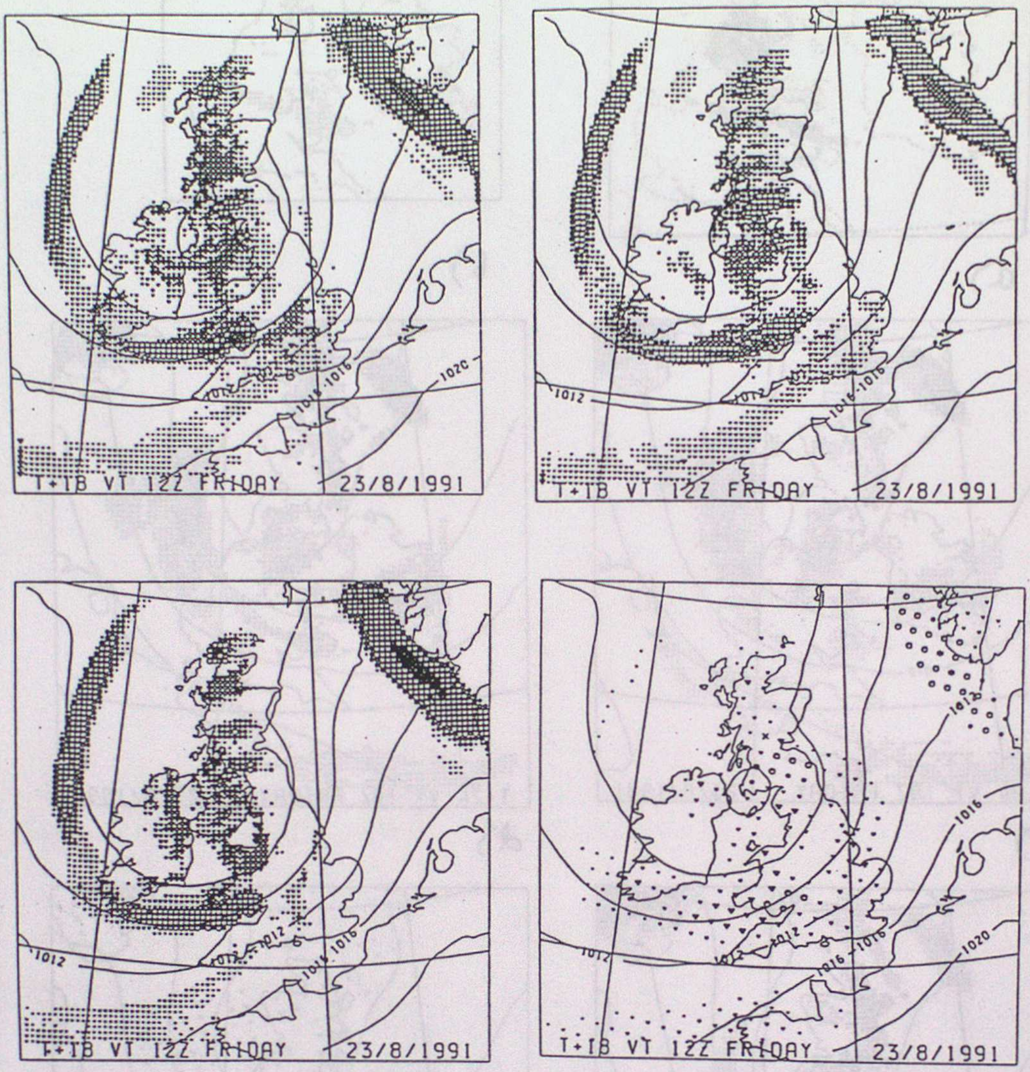


FIGURE 17. Comparison of 12 hour forecast surface precipitation rates valid at 12Z 23/8/91. Mean sea level pressure contours are also shown every 4mb.

a) NMM trial 2 and initial operational version including MOPS data. Contours and symbols as figure ..c).

b) As a) but with climate/LAM convection parameters.

c) as a) but without changes to surface roughness, convection, boundary layer or grid-scale evaporation schemes.

d) LAM vn 2.7 with changes convection, boundary layer and gridscale evaporation schemes.

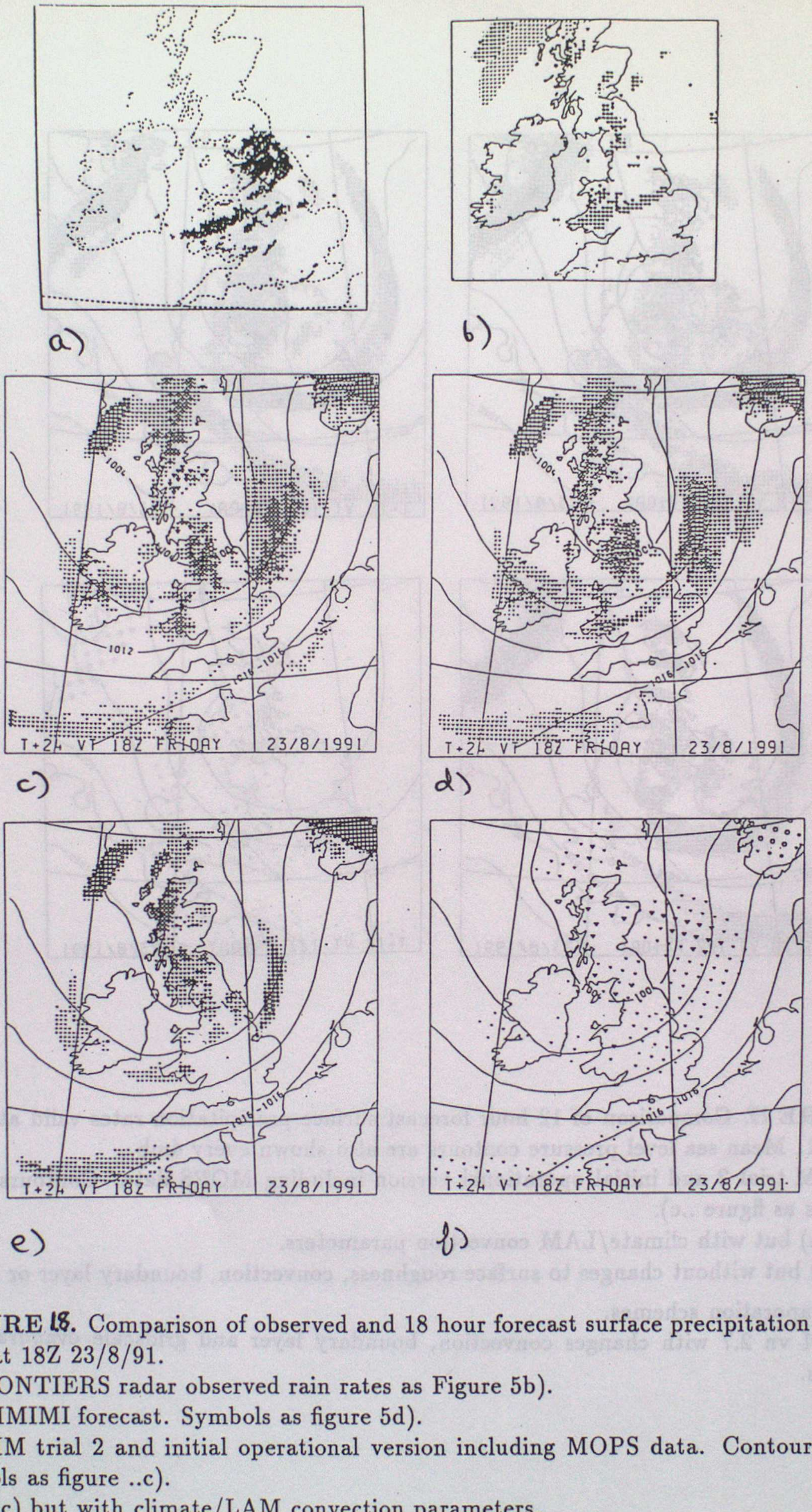


FIGURE 18. Comparison of observed and 18 hour forecast surface precipitation rates valid at 18Z 23/8/91.

a) FRONTIERS radar observed rain rates as Figure 5b).

b) OMMIMI forecast. Symbols as figure 5d).

c) NMM trial 2 and initial operational version including MOPS data. Contours and symbols as figure ..c).

d) As c) but with climate/LAM convection parameters.

e) as c) but without changes to surface roughness, convection, boundary layer or grid-scale evaporation schemes.

f) LAM vn 2.7 with changes convection, boundary layer and gridscale evaporation schemes.

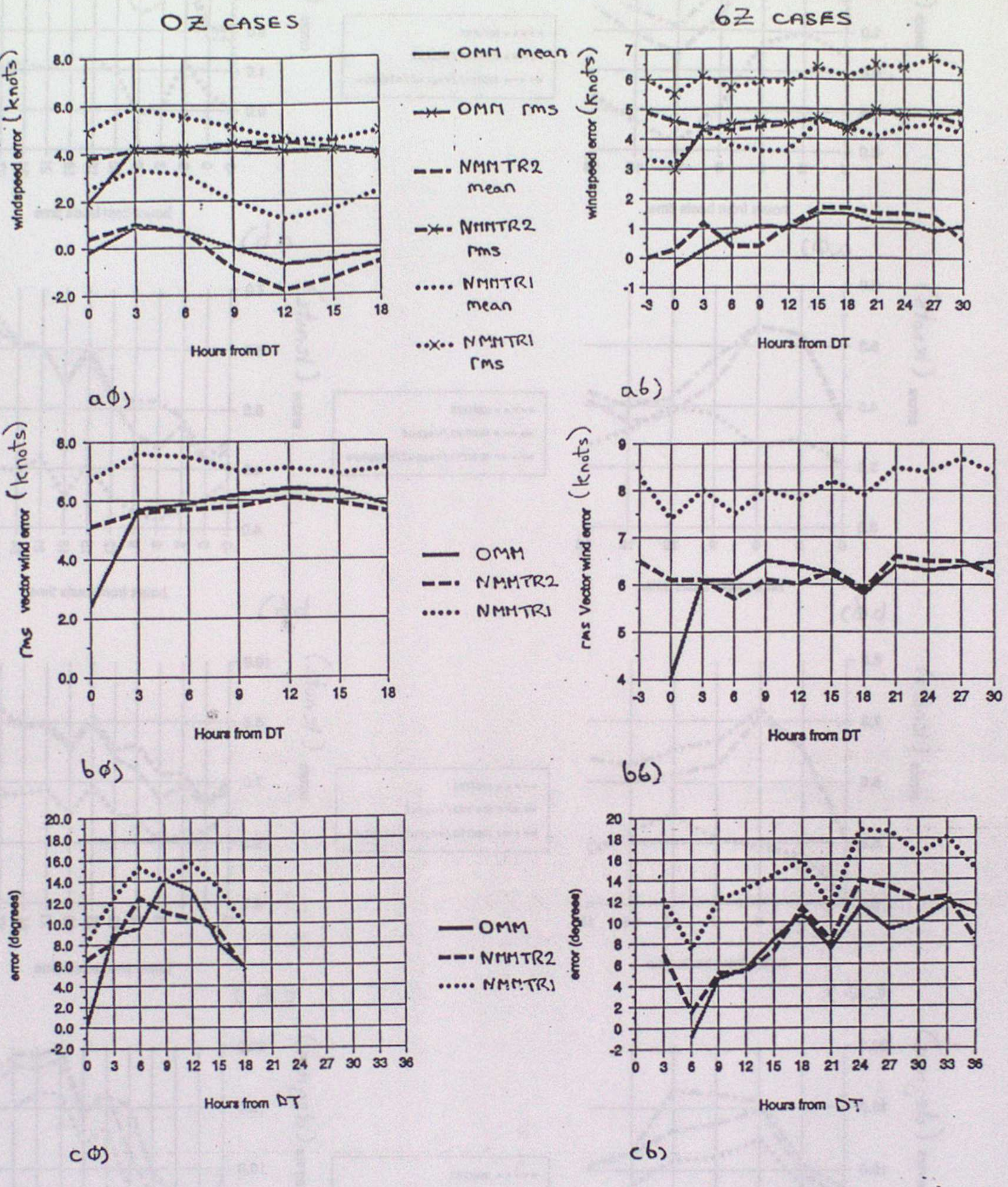


FIGURE 19. Comparison of 10m wind speed and direction direction errors for old mesoscale model (OMM) and trial 1 (NMMTR1) and trial 2 (NMMTR2) versions of new mesoscale model from the 8 trial 1 cases.

a0) and a6) mean and rms windspeed errors for 5 0Z and 3 6Z cases respectively.

b0) and b6) rms vector wind errors for 5 0Z and 3 6Z cases respectively.

c0) and c6) mean wind direction errors for 5 0Z and 3 6Z cases respectively.

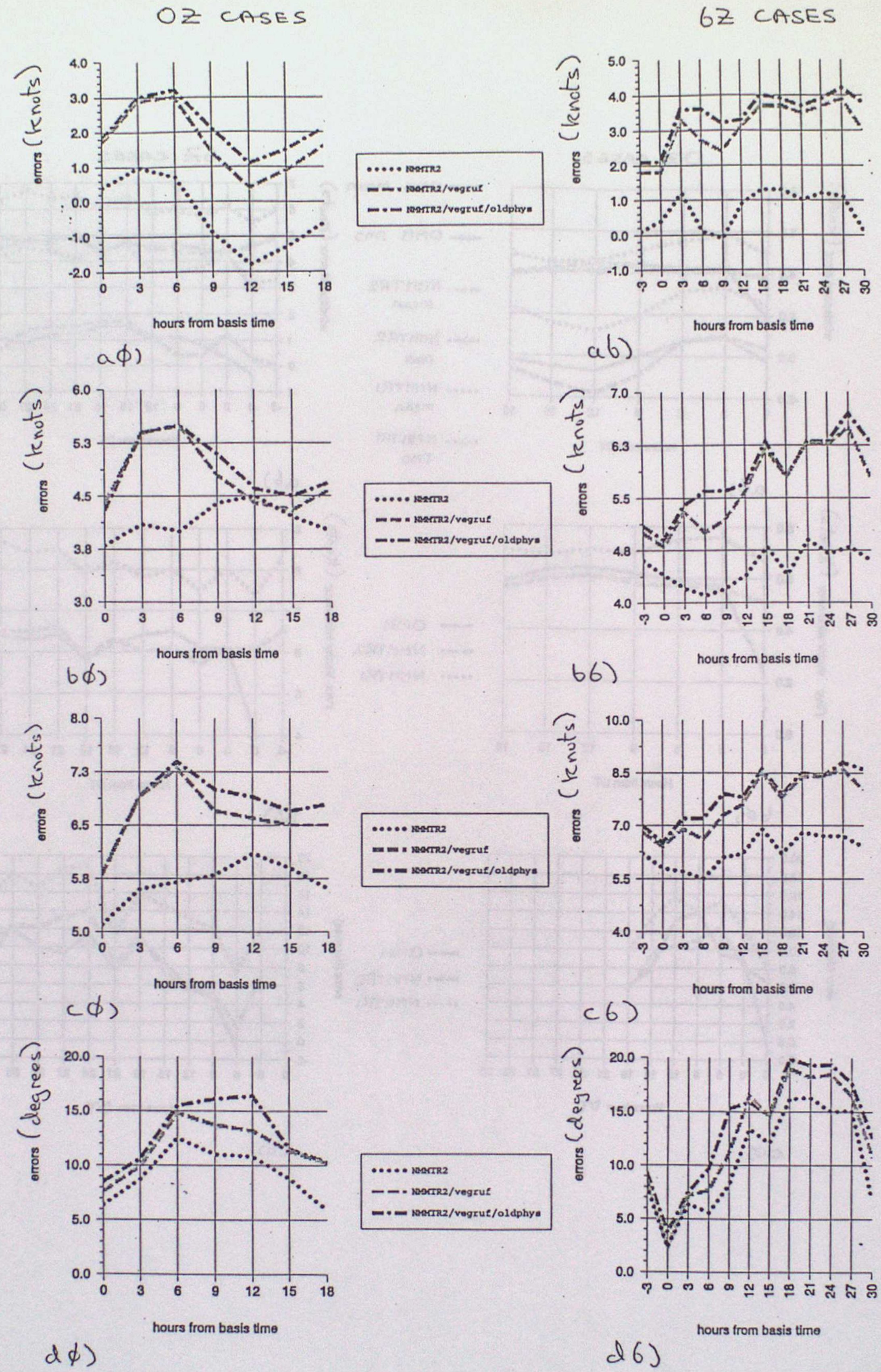


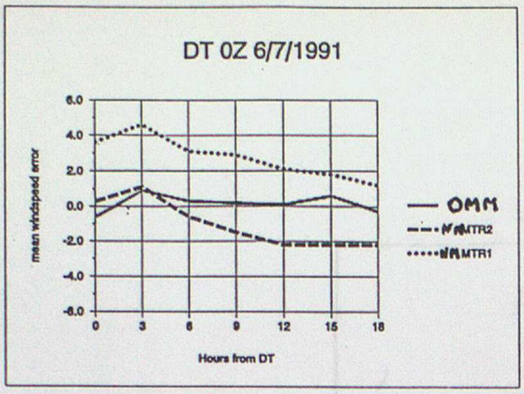
FIGURE 20. Comparison of 10m wind speed and direction direction errors for trial 2 (NMMTR2) version of new mesoscale model , trial 2 version but without modified surface roughness scheme (NMMTR2/vegruf) and trial 2 version but without modified surface roughness, convection, boundary layer and gridscale evaporation schemes (NMMTR2/vegruf/oldphys) from the 8 trial 1 cases plus 6Z 17/2/92 snow case.

a0) and a6) mean windspeed errors for 5 0Z and 4 6Z cases respectively.

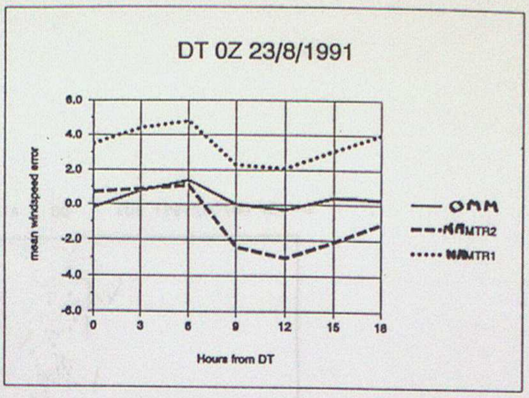
b0) and b6) rms windspeed errors for 5 0Z and 4 6Z cases respectively.

c0) and c6) rms vector wind errors for 5 0Z and 4 6Z cases respectively.

d0) and d6) mean wind direction errors for 5 0Z and 4 6Z cases respectively.



a)



b)

c)

FIGURE 21. Investigation of negative daytime windspeed bias in NMMTR2.

a) Comparison of mean windspeed errors for OMM, NMMTR1 and NMMTR2 forecasts with data time 0Z 6/7/91.

b) Comparison of mean windspeed errors for OMM, NMMTR1 and NMMTR2 forecasts with data time 0Z 23/8/91.

c) Magnitude, in knots, of difference of mean 10m windspeed errors between OMM and NMMTR2 12 hour forecasts for 12Z 23/8/91. Differences greater than 3 knots are shaded.

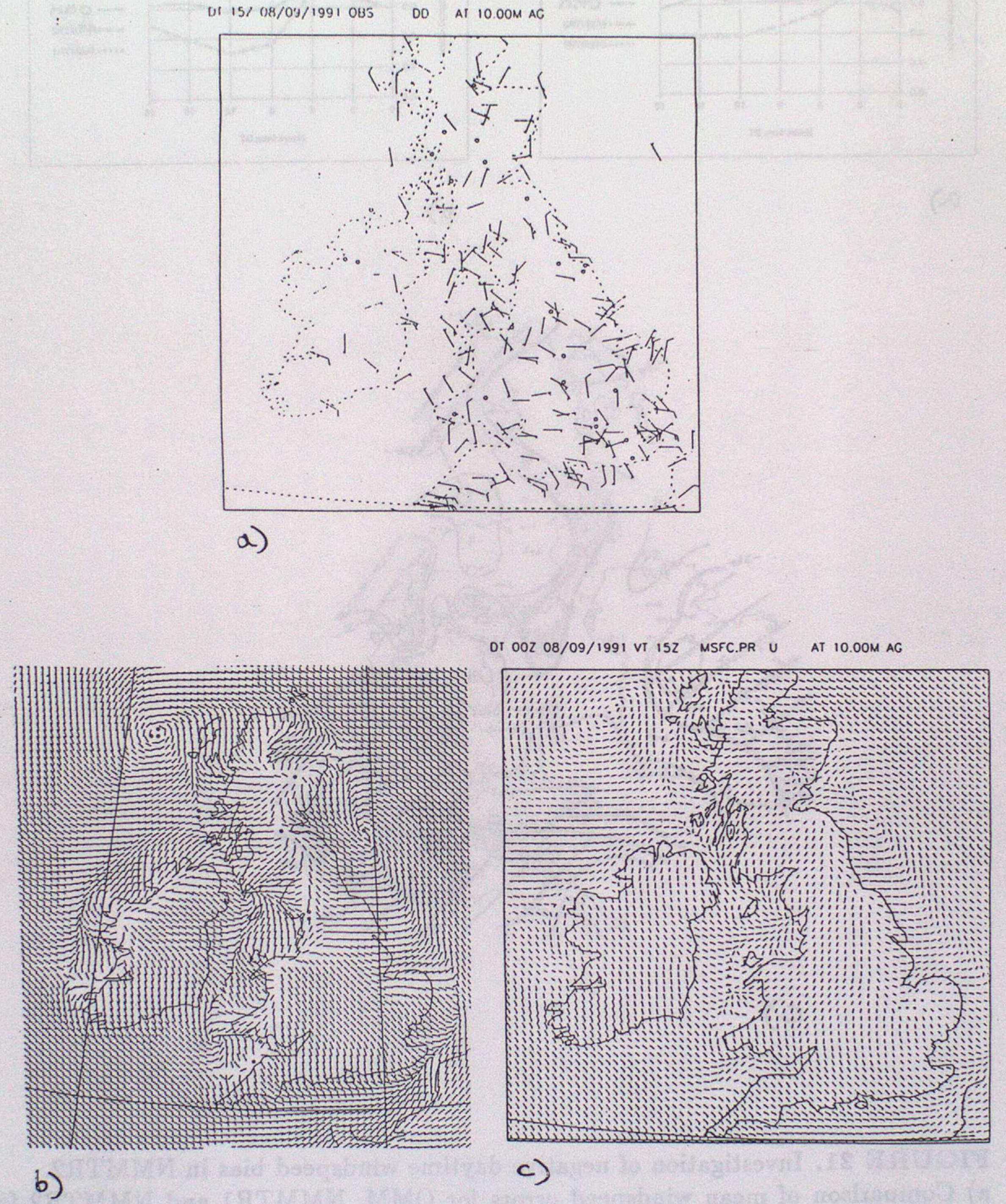


FIGURE 22. Comparison of observed and forecast 10m winds for 15Z 8/9/91.

a) Surface observations.

b) 15 hour forecast from NMMTR2.

c) 15 hour forecast from OMM.

FIGURE 23. Comparison of analysed and forecast screen temperatures at 15Z 1/9/91. Contours at 2° intervals. Shaded area is temperatures greater than 28°C and striped area is temperatures less than 14°C

a) 15 hour forecast from NMMTR2.

b) OMM operational screen temperature analysis for 15Z.

c) 15 hour forecast from NMMTR1.

d) 15 hour forecast from OMM.

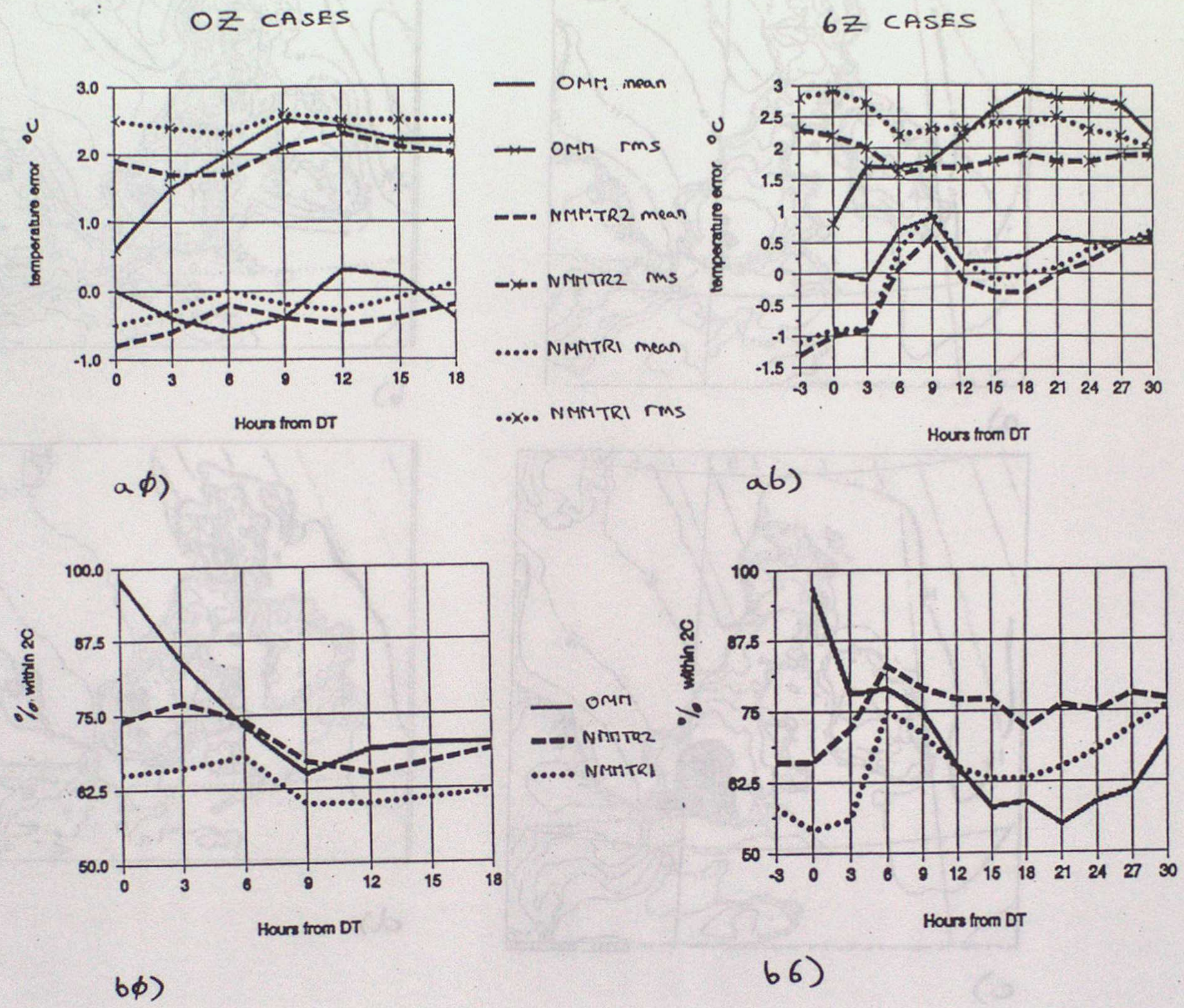


FIGURE 24. Comparison of screen temperature errors for old mesoscale model (OMM) and trial 1 (NMMTR1) and trial 2 (NMMTR2) versions of new mesoscale model from the 8 trial 1 cases. Statistics are calculated for surface reporting stations in UK area.
a0) and a6) mean and rms screen temperature errors for 5 0Z and 3 6Z cases respectively.
b0) and b6) % of forecasts within 2°C of observed values for 5 0Z and 3 6Z cases respectively.

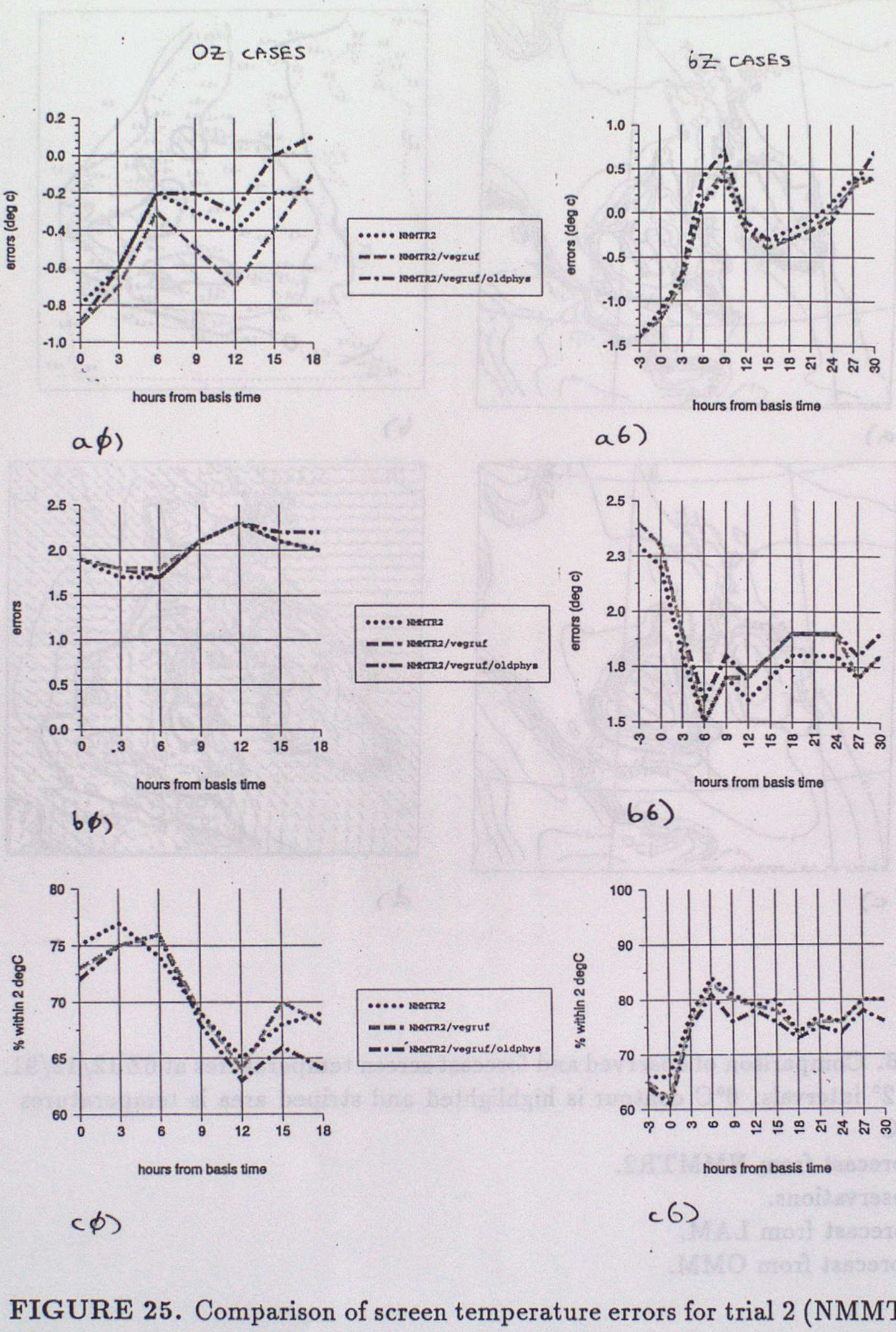


FIGURE 25. Comparison of screen temperature errors for trial 2 (NMMTR2) version of new mesoscale model , trial 2 version but without modified surface roughness scheme (NMMTR2/vegruf) and trial 2 version but without modified surface roughness, convection, boundary layer and gridscale evaporation schemes (NMMTR2/vegruf/oldphys) from the 8 trial 1 cases plus 6Z 17/2/92 snow case.

a0) and a6) mean errors for 5 0Z and 4 6Z cases respectively.

b0) and b6) rms errors for 5 0Z and 4 6Z cases respectively.

c0) and c6) % of forecasts within 2°C of observed values for 5 0Z and 4 6Z cases respectively.

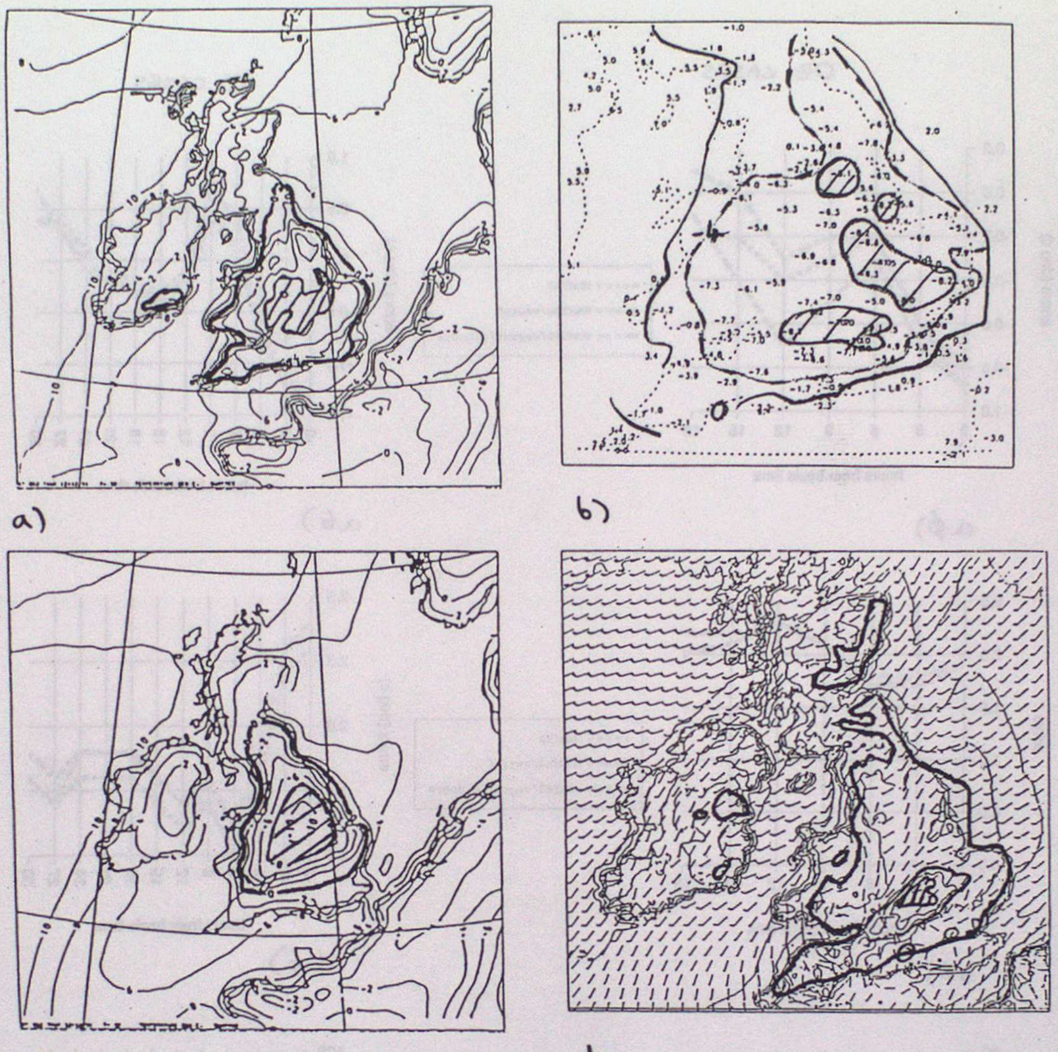


FIGURE 26. Comparison of observed and forecast screen temperatures at 6Z 12/12/91. Contours at 2° intervals. 0°C contour is highlighted and striped area is temperatures less than -8°C

a) 24 hour forecast from NMMTR2.

b) surface observations.

c) 24 hour forecast from LAM.

d) 24 hour forecast from OMM.

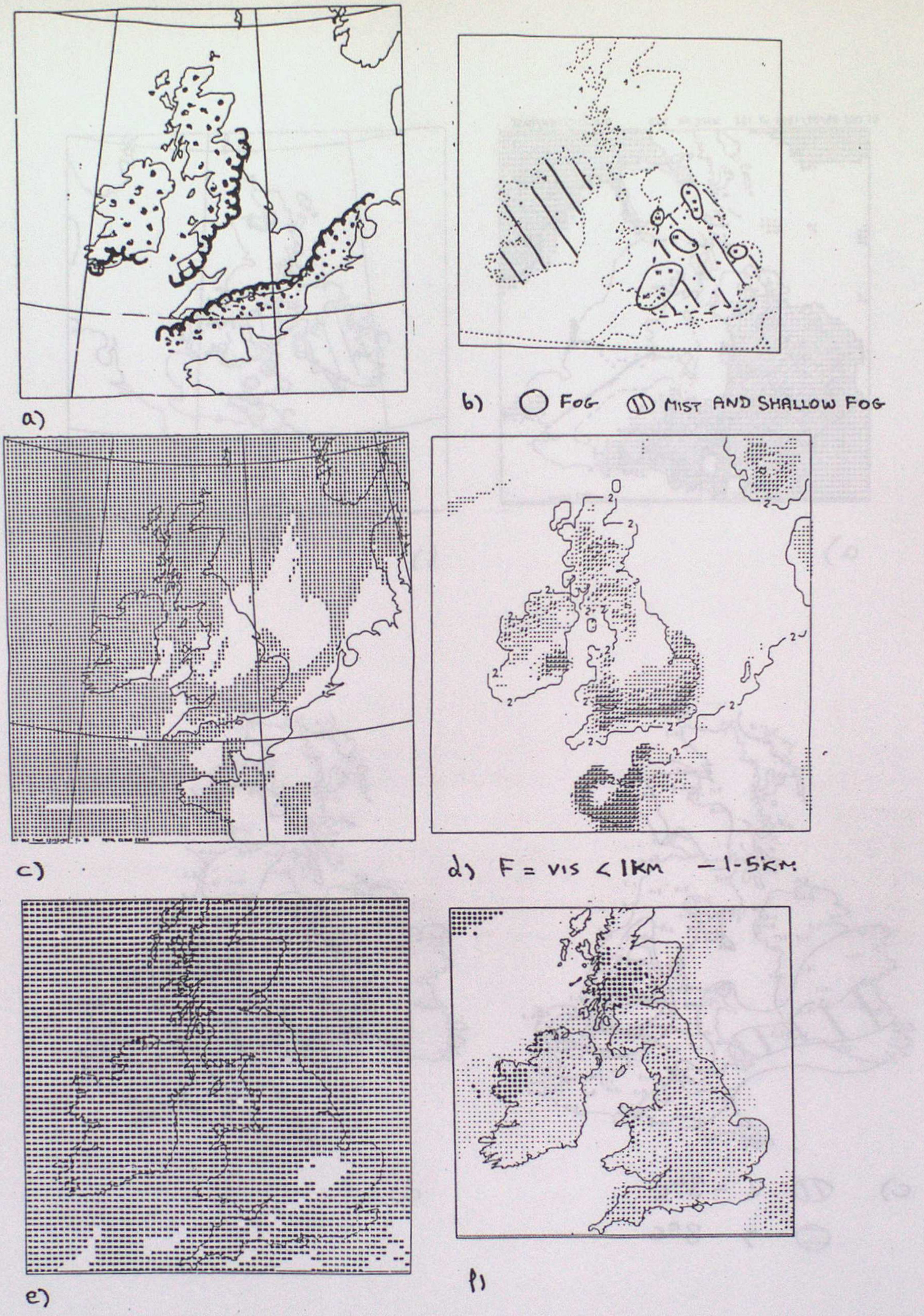


FIGURE 27. Comparison of observed and forecast total cloud cover and fog at 6Z 12/12/91. The edge of areas with greater than 3 oktas cloud cover is defined in the observations and areas with greater than 3 oktas cloud cover are shaded in the forecasts.

a) observed cloud edge
b) observed present weather, areas of fog and mist marked
c) NMMTR2 24 hour forecast of total cloud cover
d) NMMTR2 24 hour forecast of fog and low visibility
e) operational OMM 24 hour forecast of total cloud cover
f) operational OMM 24 hour forecast of present weather, fog and low visibility symbols as d)

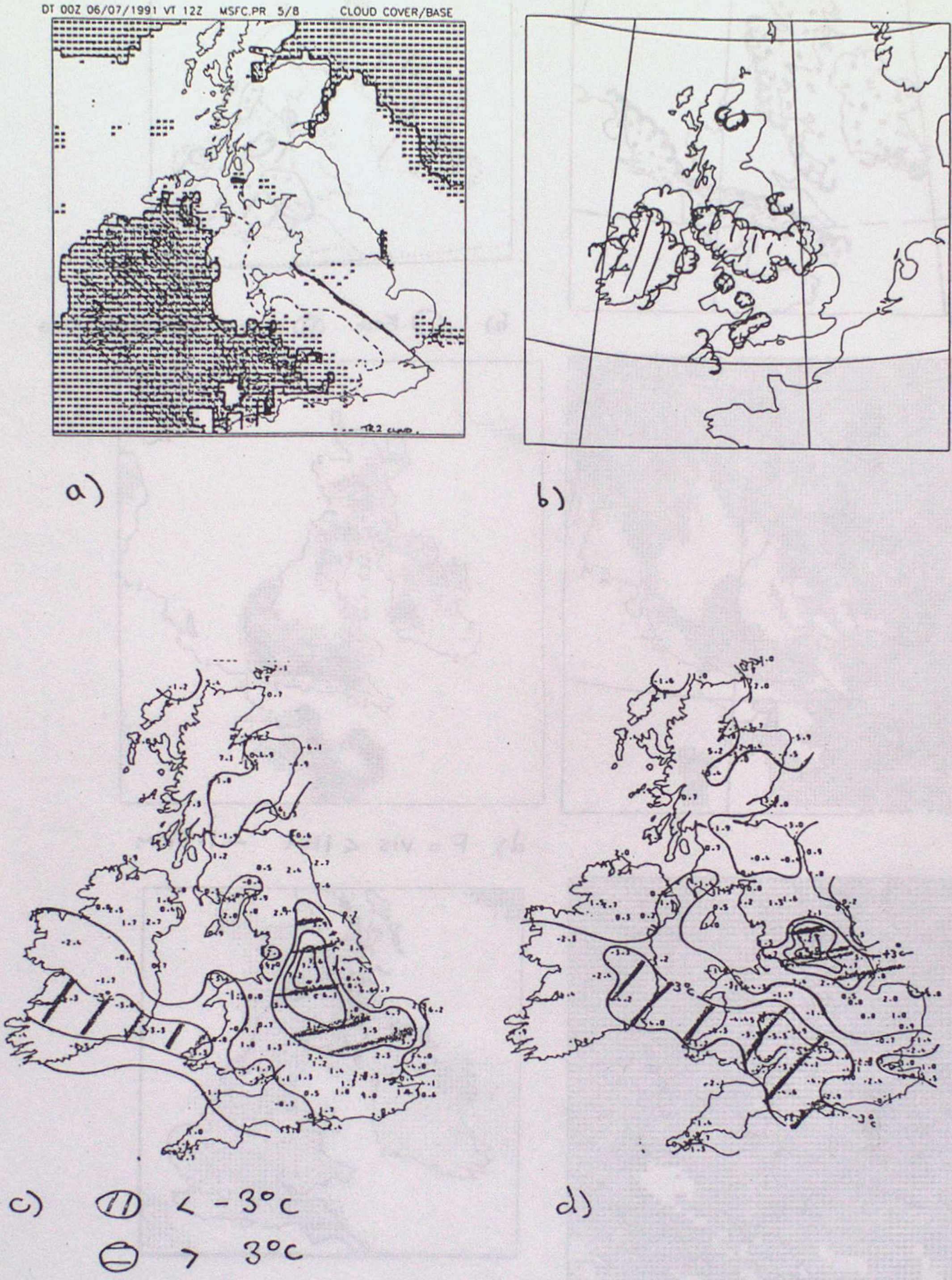


FIGURE 28. Investigation of screen temperature errors in 0Z 6/7/91 forecast.

a) 12 hour forecast cloud cover from OMM valid at 12Z 6/7/91, areas with greater than 5 oktas shaded. Edge of greater than 5 oktas in NMMTR2 marked with dashed line. Easternmost extent of cloud in NMMTR2 at 6Z 6/7/91 shown by solid line.

b) Observed cloud cover.

c) Horizontal distribution of errors in 12 hour screen temperature forecast from OMM valid at 12Z 6/7/91.

d) Horizontal distribution of errors in 12 hour screen temperature forecast from NMMTR2 valid at 12Z 6/7/91.

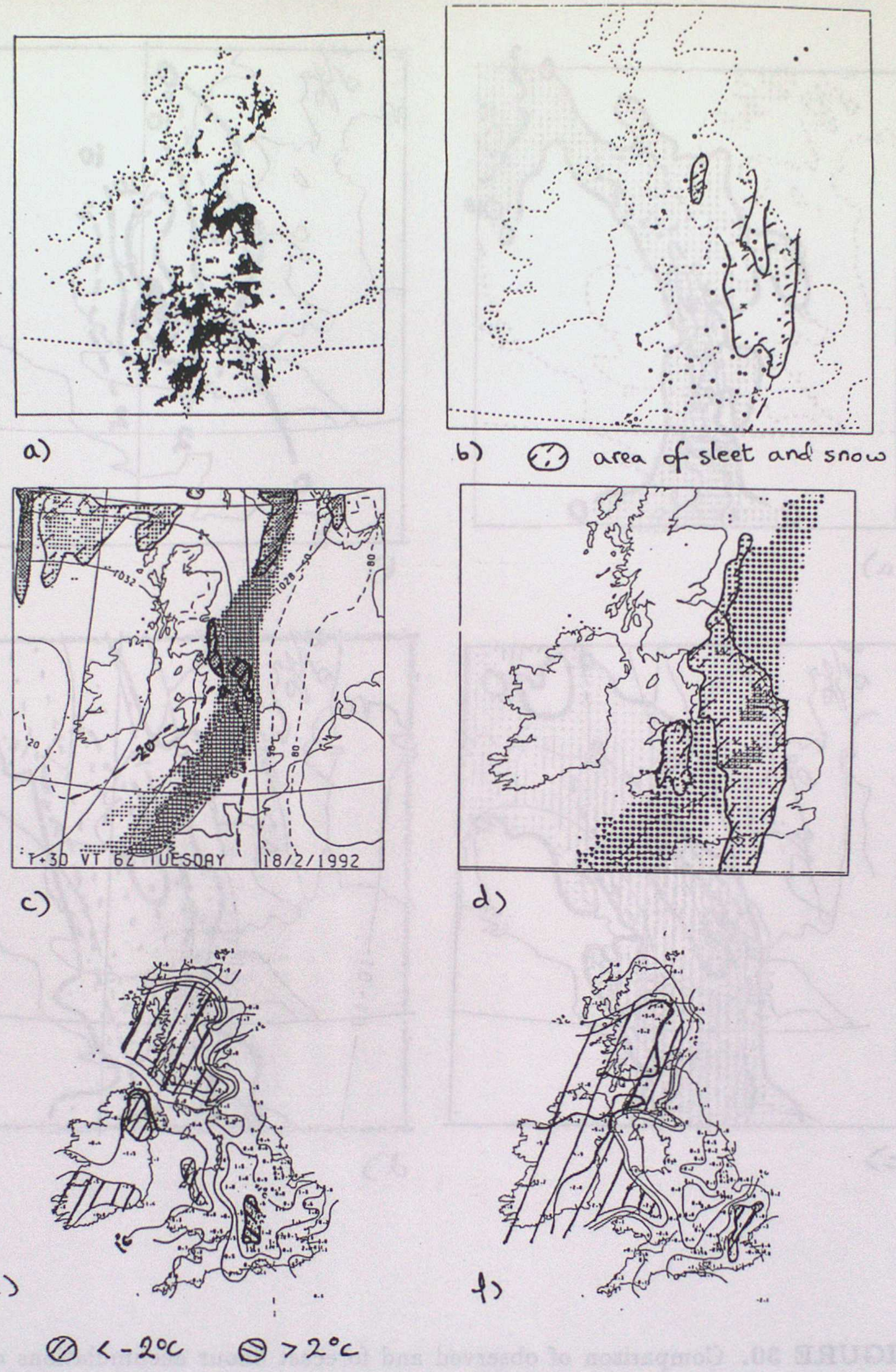


FIGURE 29. Investigation of snow prediction in 6Z 17/2/92 forecast.
a) FRONTIERS radar observed precipitation rates at 6Z 18/2/92. Black areas have rates greater than 0.125mm/hour.
b) Surface present weather reports at 6Z 18/2/92. Circles are observed rain and crosses and asterixes are sleet or snow of different intensities.
c) 24 hour forecast from NMMTR2. Solid contours show pmsl, dashed contours show snow probability in %. Dots and circles show location of forecast rain, crosses show location of forecast snow. Areas of forecast snow are also shaded.
d) 24 hour forecast from OMM. Dots and circles show location of forecast rain, crosses and asterixes show location of forecast snow. Areas of forecast snow are also shaded.
e) Horizontal distribution of errors in 24 hour screen temperature forecast from NMMTR2 valid at 6Z 18/2/92.
f) as e) but for OMM.

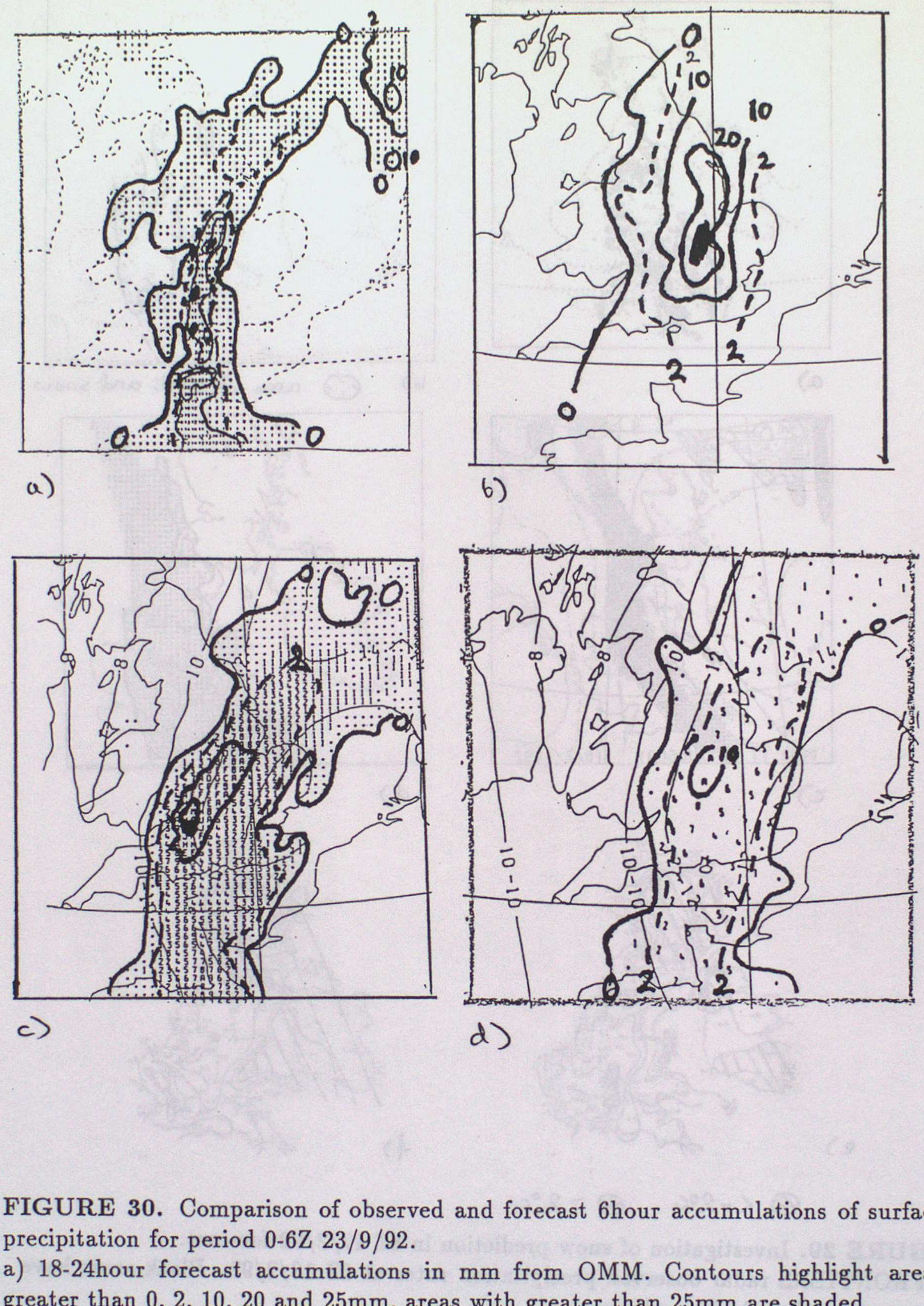


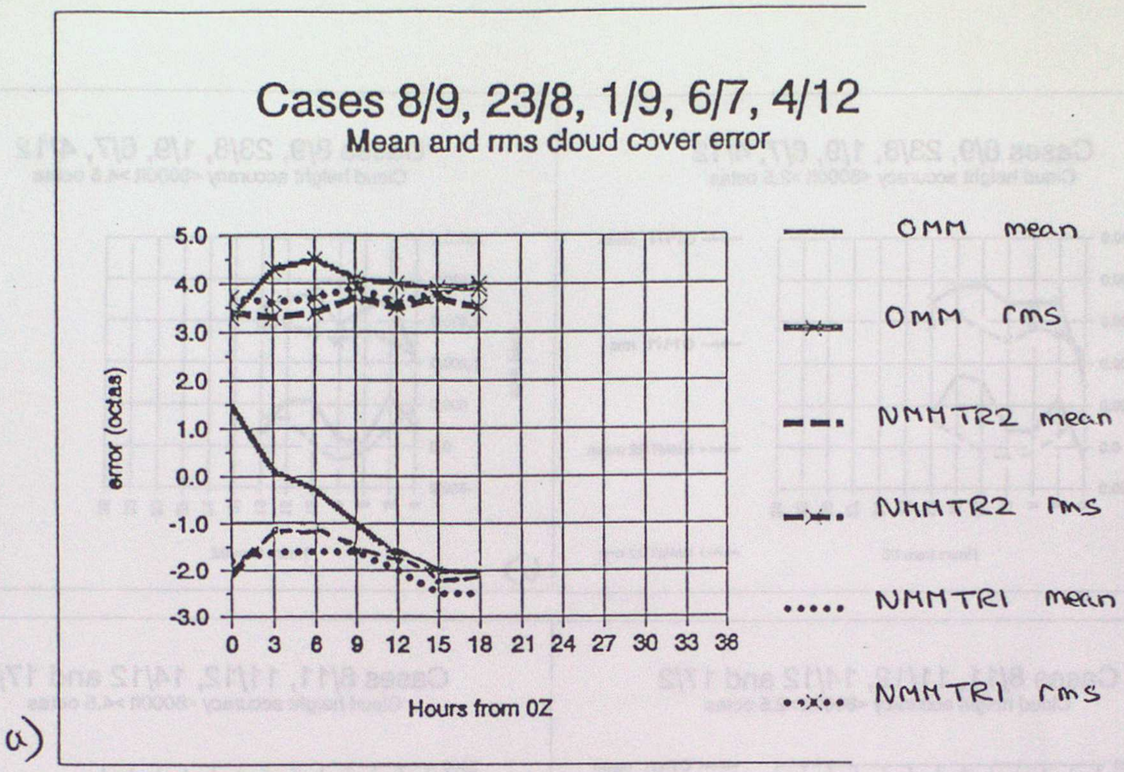
FIGURE 30. Comparison of observed and forecast 6hour accumulations of surface precipitation for period 0-6Z 23/9/92.

a) 18-24hour forecast accumulations in mm from OMM. Contours highlight areas greater than 0, 2, 10, 20 and 25mm, areas with greater than 25mm are shaded.

b) Surface observations of accumulations in mm. Contours and shading as a).

c) As a) but for NMMTR2. Light contours are 850mb wet bulb potential temperature °C.

d) As c) but for LAM with new physics.



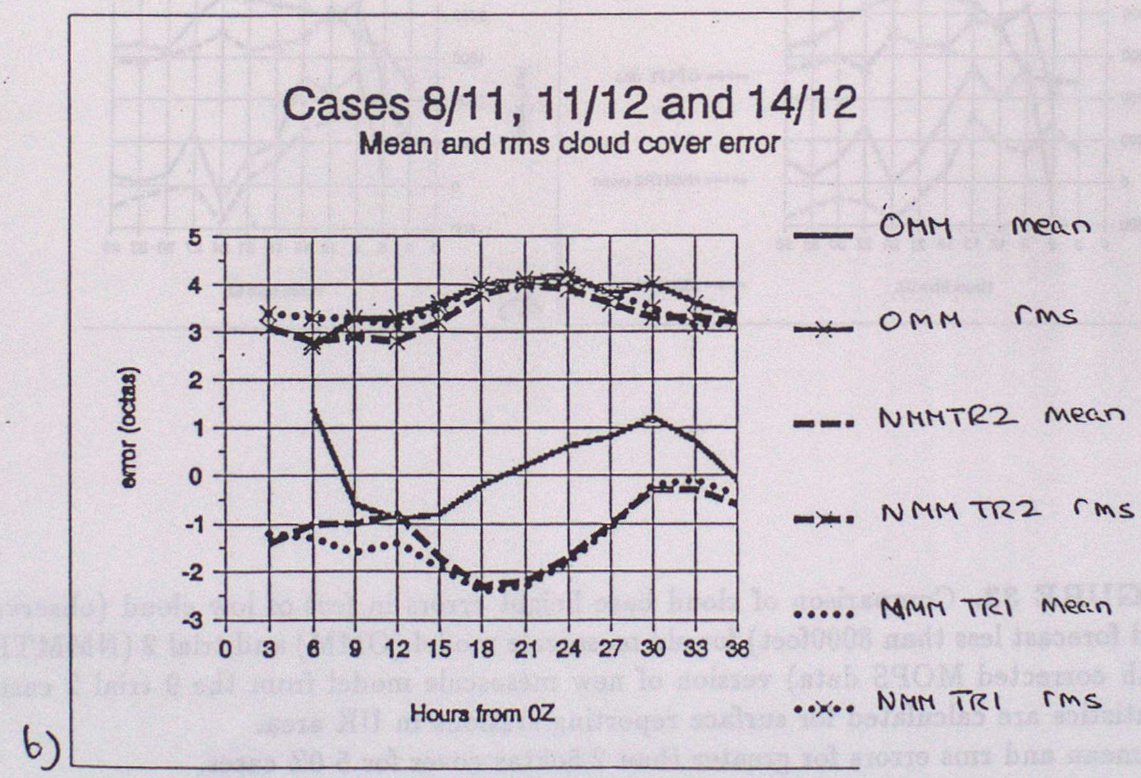


FIGURE 31. Comparison of cloud cover errors in oktas for old mesoscale model (OMM) and trial 1 (NMMTR1) and trial 2 (NMMTR2 with corrected MOPS data) versions of new mesoscale model from the 8 trial 1 cases. Statistics are calculated for surface reporting stations in UK area.

a) mean and rms errors for 5 0Z cases.

b) mean and rms errors for 3 6Z cases.

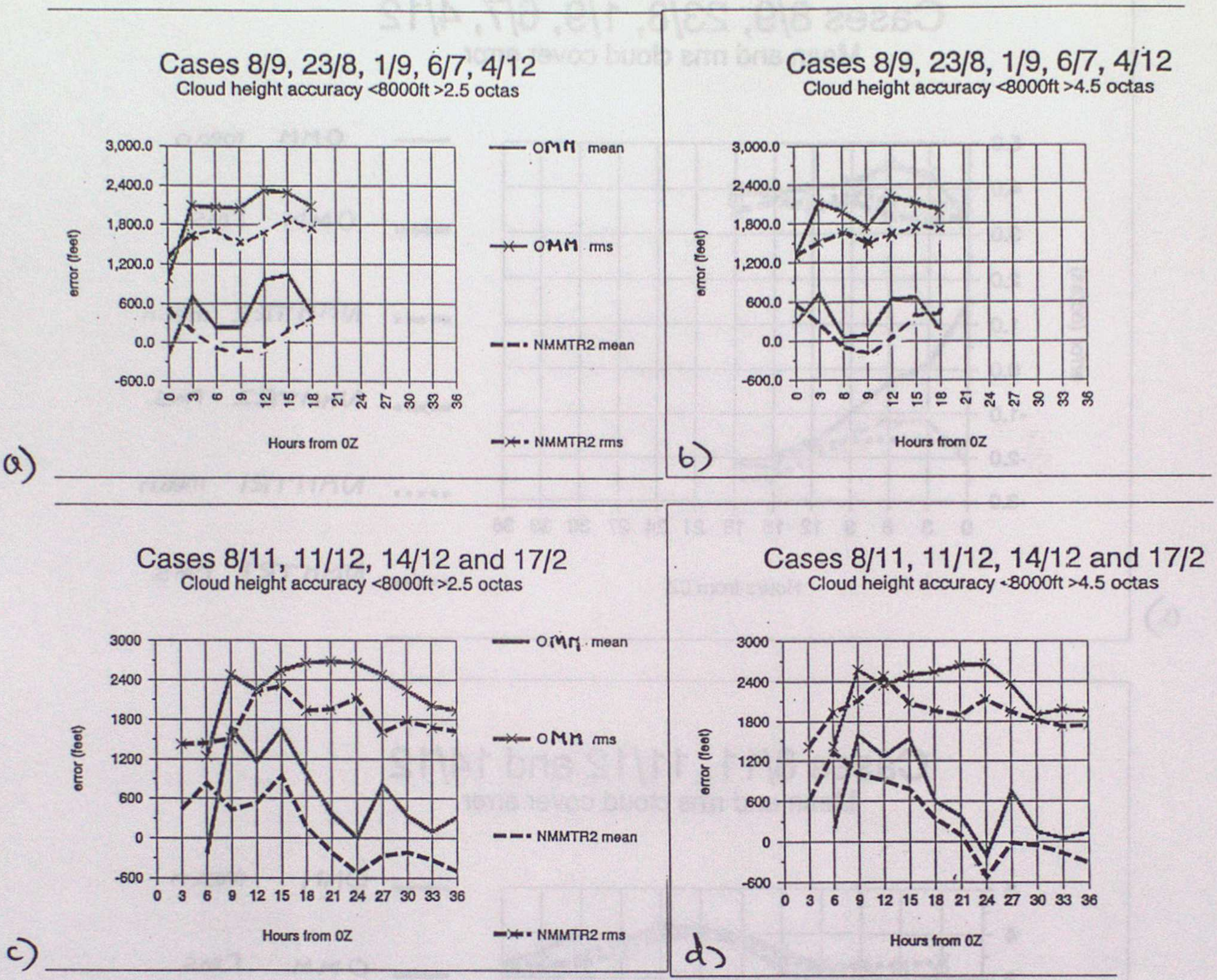


FIGURE 32. Comparison of cloud base height errors in feet of low cloud (observed and forecast less than 8000feet) for old mesoscale model (OMM) and trial 2 (NMMTR2 with corrected MOPS data) version of new mesoscale model from the 9 trial 2 cases. Statistics are calculated for surface reporting stations in UK area.

a) mean and rms errors for greater than 2.5oktas cover for 5 0Z cases.

b) mean and rms errors for greater than 4.5oktas cover for 5 0Z cases.

c) mean and rms errors for greater than 2.5oktas cover for 4 6Z cases.

d) mean and rms errors for greater than 4.5oktas cover for 4 6Z cases.

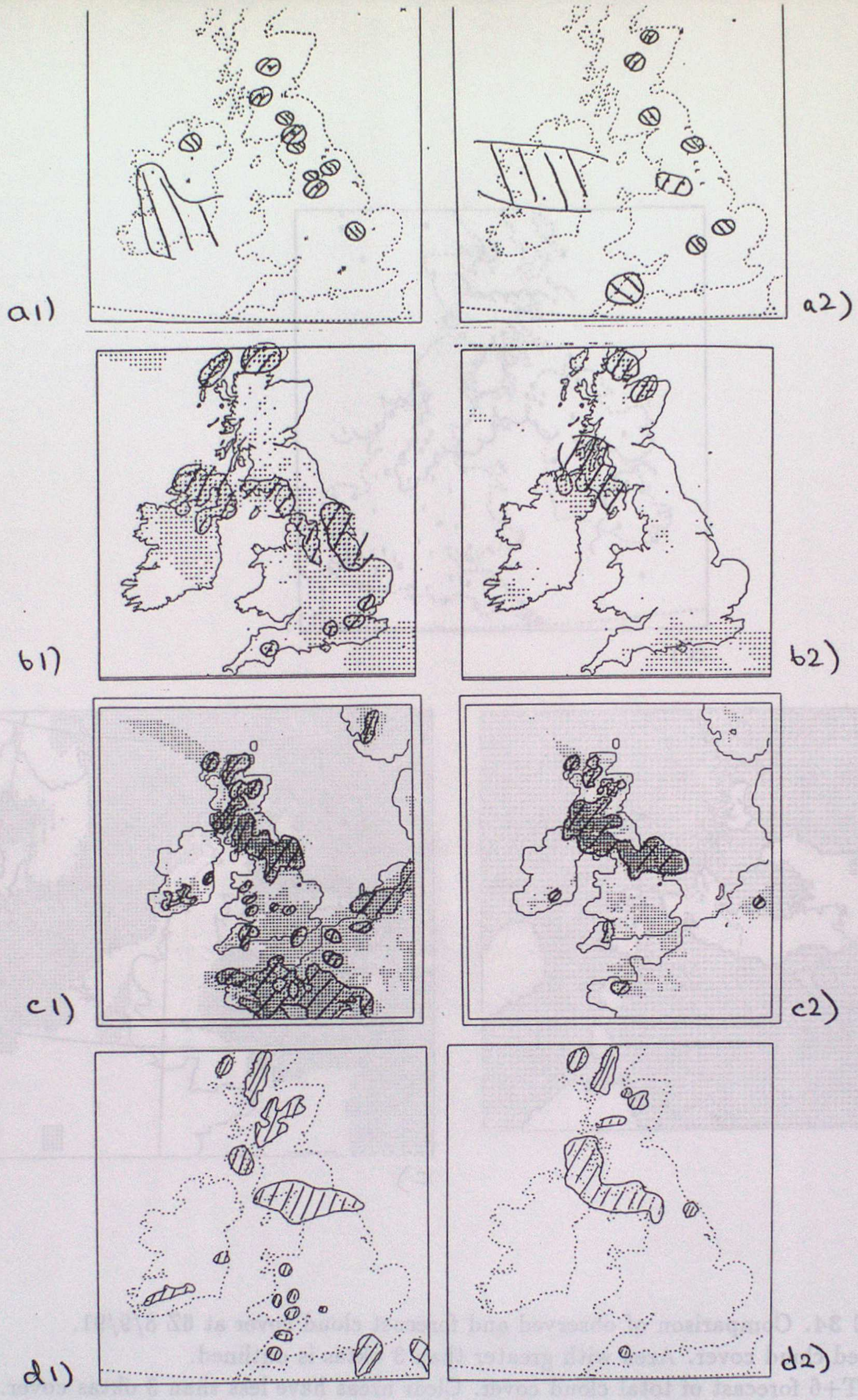


FIGURE 33. Comparison of observed and forecast mist and fog for 4/12/91 case.
a1) Observed mist and fog at 9Z 4/12/91 based on present weather reports.
\\ mist and shallow fog, // fog
a2) as a1) but for 15Z 4/12/91.
b1) OMM T+9 forecast of visibility for 9Z 4/12/91.
// fog, - visibility 1-5km.
b2) as b1 but T+15 forecast for 15Z 4/12/91.
c1) as b1) but for NMMTR2 with erroneous MOPS data.
c2) as b2) but for NMMTR2 with erroneous MOPS data.
d1) as b1) but for NMMTR2 with corrected MOPS data. Only fog shown
d2) as b2) but for NMMTR2 with corrected MOPS data. Only fog shown

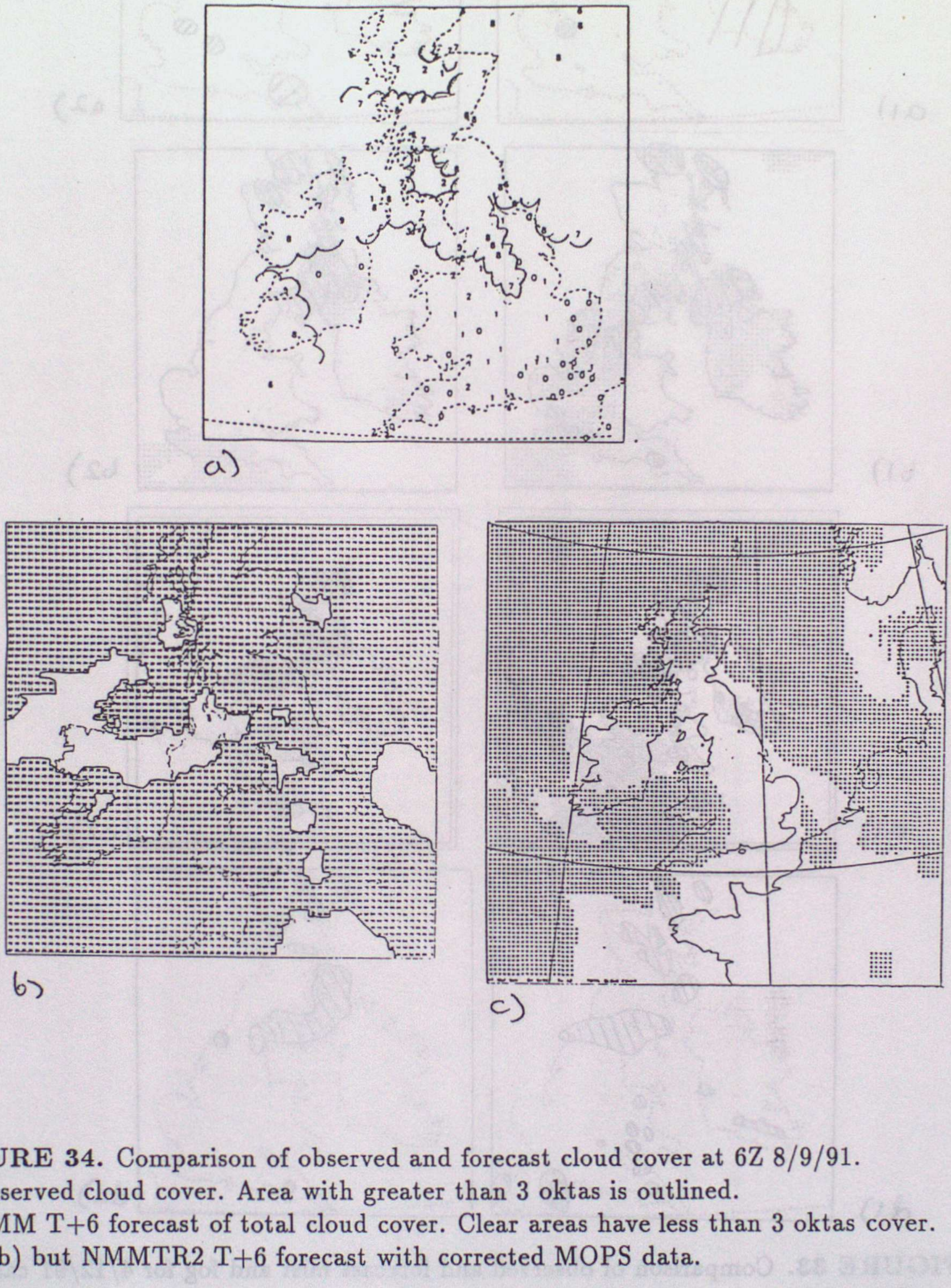


FIGURE 34. Comparison of observed and forecast cloud cover at 6Z 8/9/91.

a) Observed cloud cover. Area with greater than 3 oktas is outlined.

b) OMM T+6 forecast of total cloud cover. Clear areas have less than 3 oktas cover.

c) as b) but NMMTR2 T+6 forecast with corrected MOPS data.

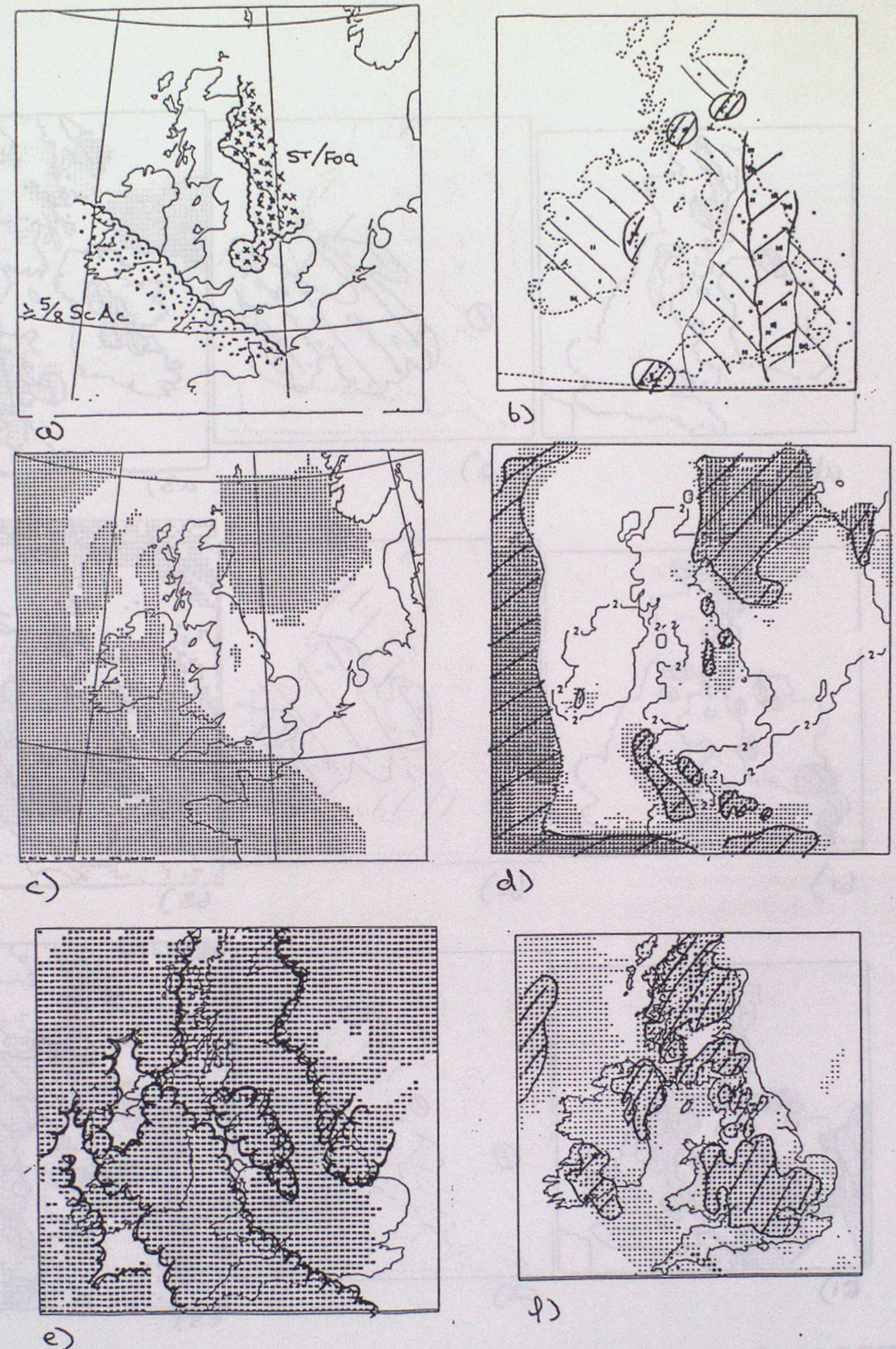


FIGURE 35. Comparison of observed and forecast cloud cover and fog at 6Z 1/9/91.
a) Observed cloud cover. Area with greater than 3 oktas is shaded.
b) Observed mist and fog based on present weather reports.
\\ mist and shallow fog, // fog
c) NMMTR2 with corrected MOPS data, T+6 forecast of total cloud cover. Clear areas have less than 3 oktas cover.
d) as c) but T+6 forecast of visibility.
// fog, - visibility 1-5km.
e) as c) but OMM T+6 forecast. Area of cloud with base above surface is outlined
f) as d) but OMM T+6 forecast.

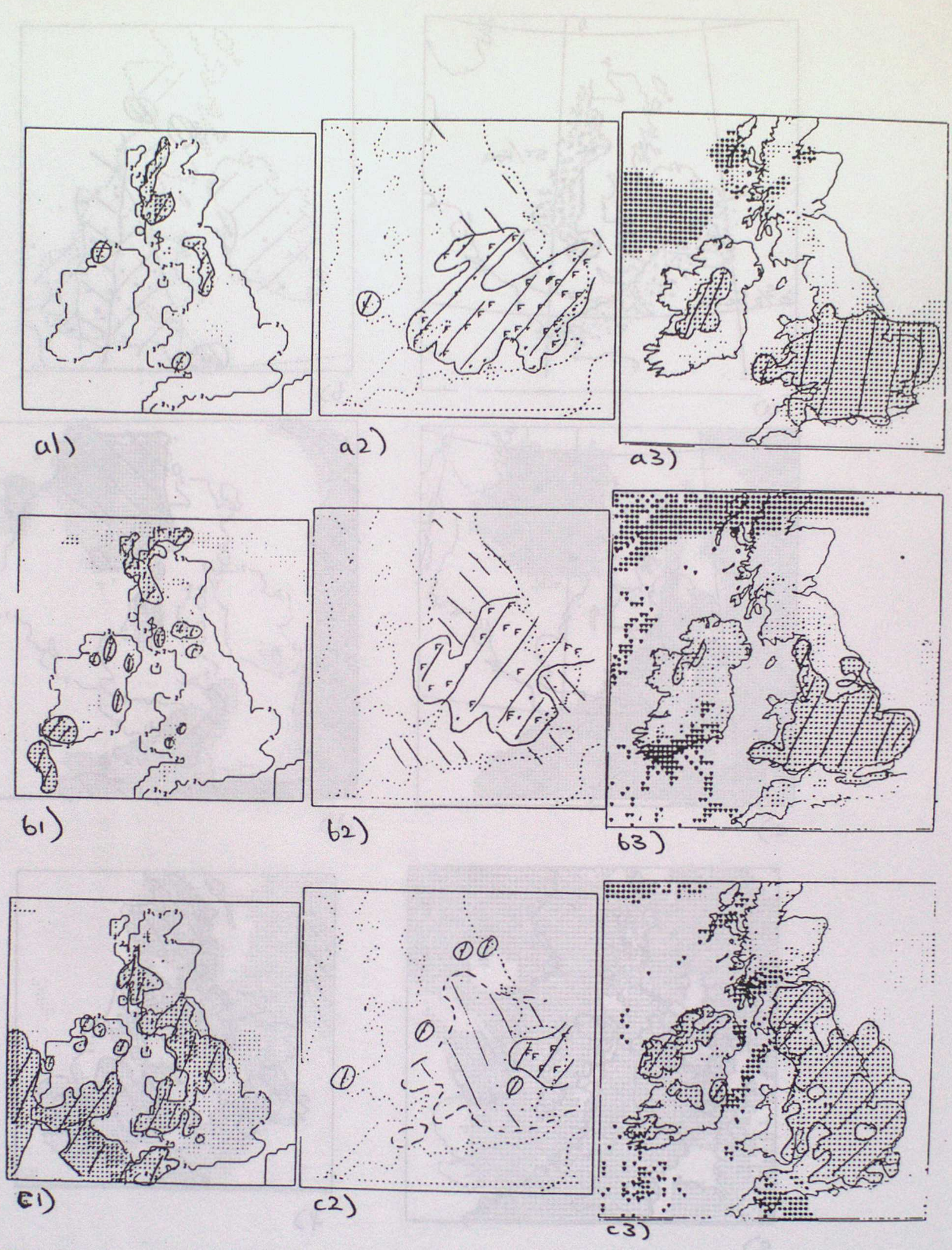


FIGURE 36. Comparison of observed and forecast fog during period 6Z 14/12/91 to 6Z 15/12/91.
a1) to a5) 6Z 14/12/91.
a1) NMMTR1 analysis ie T+0 forecast, of visibility.
// fog, - visibility 1-5km.
a2) Observed mist and fog based on present weather reports.
\\ mist and shallow fog, // fog
a3) OMM analysis of present weather. Dots are precipitation, otherwise as a1)
a4) as a1) but NMMTR2 analysis.
a5) NMMTR2 analysis of total cloud cover. Clear areas have less than 3 oktas cover.
b1) to b5) as a1) to a5) but for 18Z 14/12/91, T+12 forecasts
c1) to c5) as a1) to a5) but for 6Z 15/12/91, T+24 forecasts

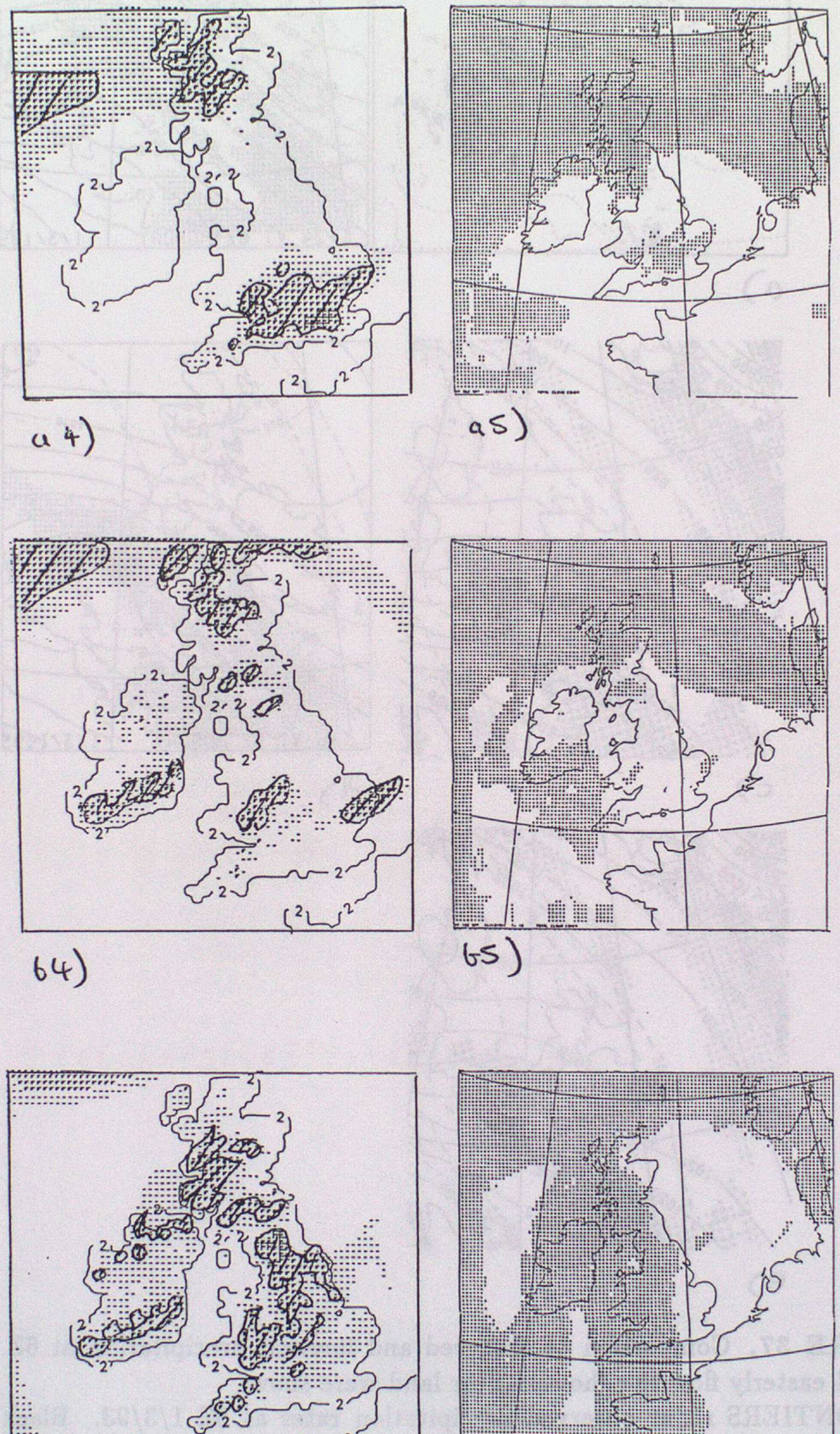


FIGURE 36. Continued.

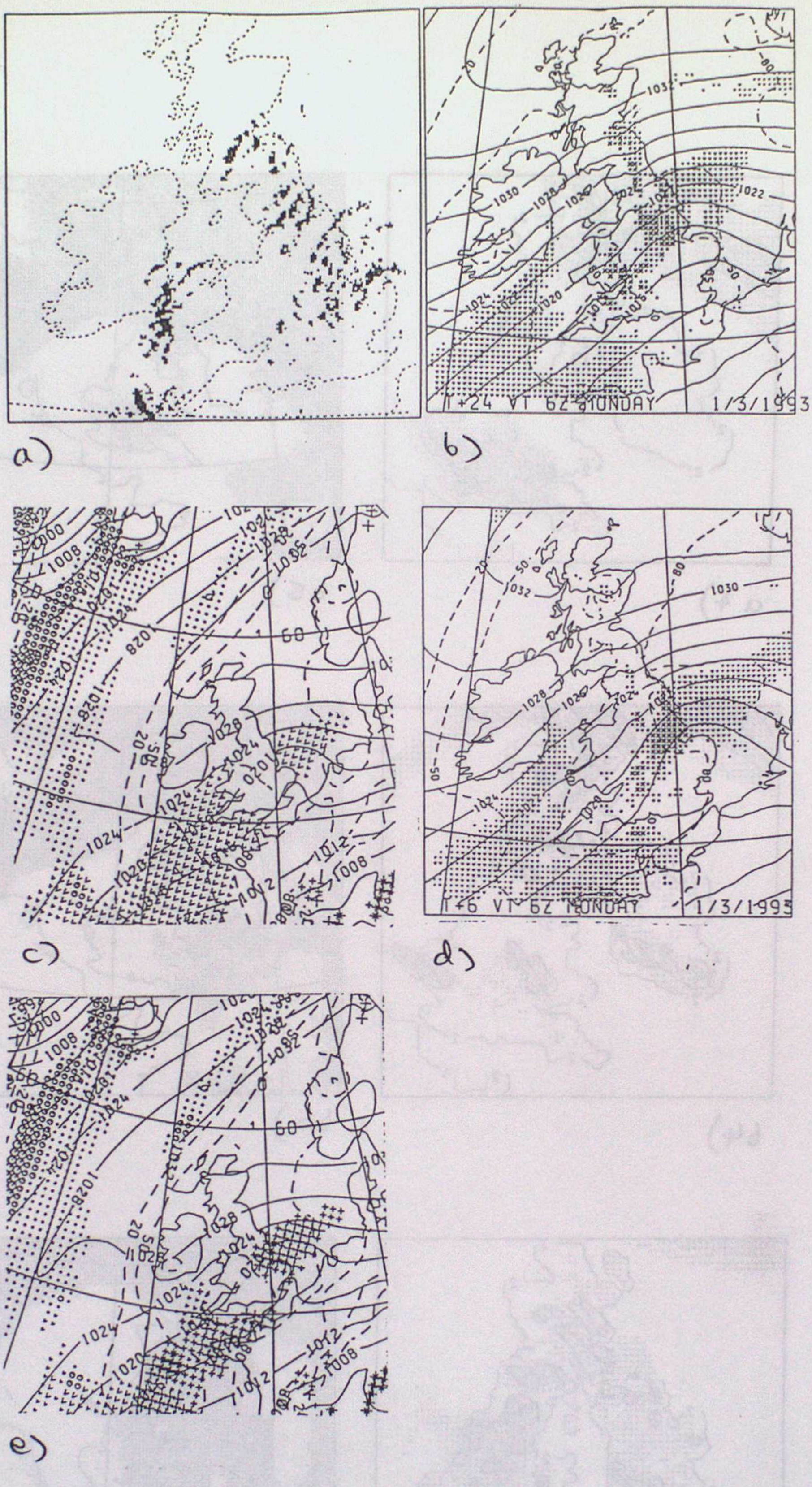


FIGURE 37. Comparison of observed and forecast precipitation at 6Z 1/3/93. In the cold easterly flow the showers over land were snow.

a) FRONTIERS radar observed precipitation rates at 6Z 1/3/93. Black areas have rates greater than 0.125mm/hour.

b) 24 hour forecast from 6Z 28/2/93 operational NMM. Solid contours show pmsl, dashed contours show snow probability in %. Dots and circles show location of forecast rain, v shows location of convection, crosses show location of forecast snow - in this case convective.

c) as b) but T+6 forecast from 0Z 1/3/93 operational LAM.

d) as b) but T+6 forecast from 0Z 1/3/93 operational NMM.

e) as c) but T+6 forecast from 0Z 1/3/93 LAM rerun with new physics.

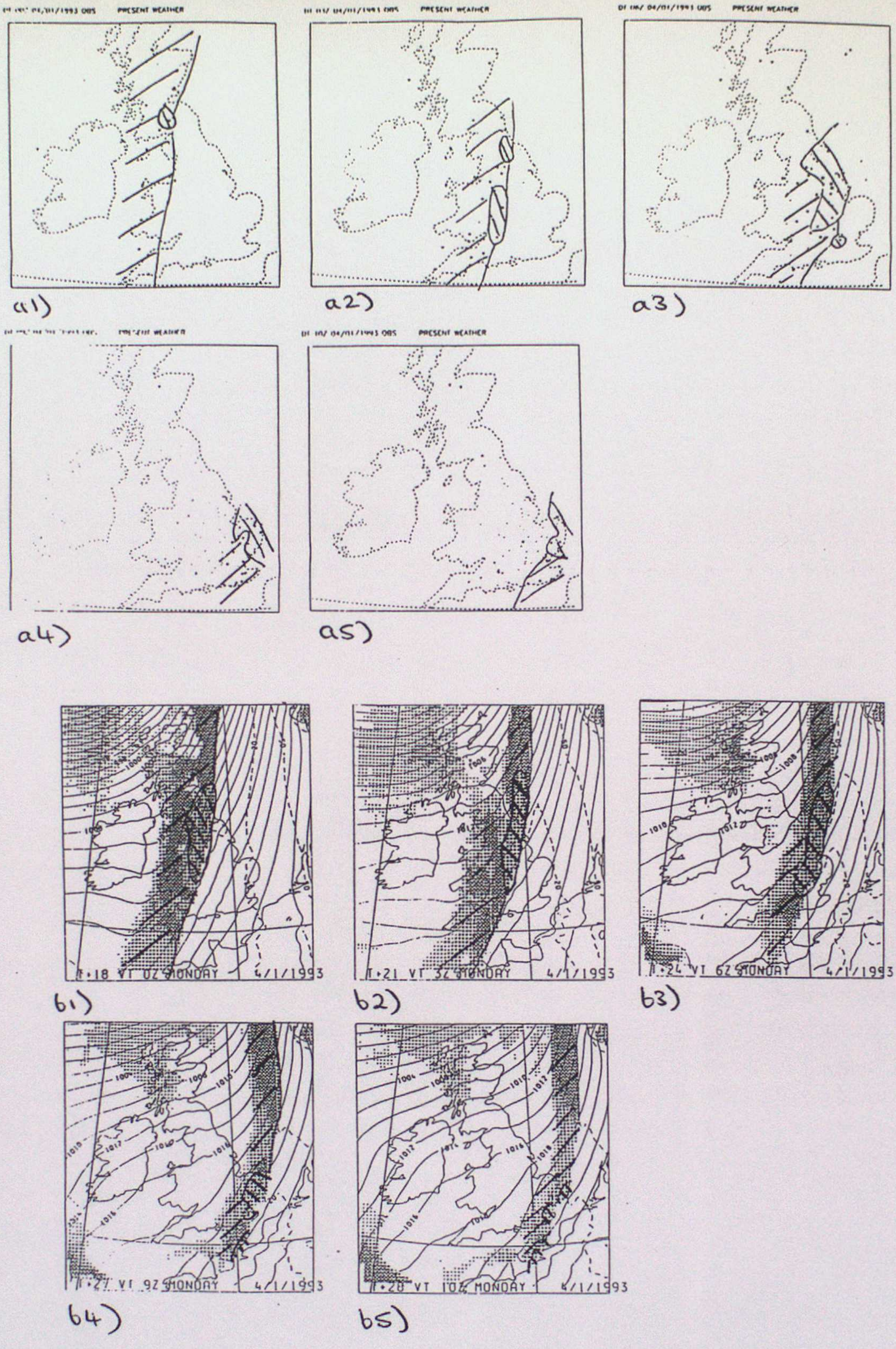


FIGURE 38. Comparison of observed and forecast precipitation 4/1/93.
a1-a5) Surface present weather reports at 0Z, 3Z, 6Z, 9Z and 10Z 4/1/93 respectively.
\\ sleet and snow, // rain
b1-b5) T+18,T+21,T+24,T+27and T+28 hour forecasts from 6Z 3/1/93 operational NMM. Solid contours show pmsl, dashed contours show snow probability in %. Dots and circles show location of forecast rain, crosses show location of forecast snow. Areas of forecast snow and rain are also shaded.
\\ snow, // rain

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