Numerical Weather Prediction

Implementation of New Dynamics in the UK Mesoscale Model

Forecasting Research Technical Report No. 434

Clive Wilson, Stephen Cusack, Byron Chalcraft,
Martin Goeber, Jorge Bornemann, Bruce Macpherson,
Richard Renshaw, Adam Maycock, Nicola Robertson

email: nwp_publications@metoffice.com

Forecasting Research Technical Report No. 434

Implementation of New Dynamics in the UK Mesoscale Model

by

Clive Wilson, Stephen Cusack, Byron Chalcraft, Martin Goeber, Jorge Bornemann, Bruce Macpherson, Richard Renshaw, Adam Maycock, Nicola Robertson

February 6th 2004

Abstract

A major upgrade to the Met Office's operational Numerical Weather Prediction models took place on 7th August 2002, when a package of changes known as 'New Dynamics' (ND) was introduced. Both global and UK Mesoscale (Mes) configurations were revised. This report documents the pre-implementation trials of the UK Mes version. Trials of ND in the UK Mes involved 15 selected cases covering a range of weather types and a period of several months continuous parallel running in the 'shadow' suite.

Relative to the control 'Old Dynamics' (OD) version operational at the time, the *objective verification* of Mes ND showed a slight improvement in visibility, a slight degradation in rainfall and an overall signal in UK index variables that was slightly positive in case studies and slightly negative in extended parallel running. Smaller biases were found in ND for screen temperature, screen relative humidity and 10-metre wind. Spin-up of cloud and precipitation was reduced in ND.

A broadly neutral picture was seen in the *subjective assessment* of both the case studies and parallel suite output, with the ND runs slightly favoured, mainly for the improved handling in some situations of precipitation, low cloud and fog probability.

Overall, this initial version of Mes ND was judged to have an impact not significantly different from neutral and to provide a very significant foundation on which to build further improvements in high resolution modelling.

1. Introduction

A major upgrade to the Met Office's operational Numerical Weather Prediction models took place on 7th August 2002, when a package of changes known as 'New Dynamics' (ND) was introduced. Both global and UK Mesoscale (Mes) configurations were revised. For a description of the main components of global ND, see the Appendix. An overview of the numerical methods within ND is given by Cullen et al. (1997). This report documents the pre-implementation trials of the UK Mes version.

1.1 The Mesoscale New Dynamics version

1.1a The Model

The Mes version trialled was as close as possible to that of global ND, but did not include some modifications to the convection and boundary layer interaction which were developed to improve the representation of convection in the tropics. These will be trialled for future Mes upgrades. Other differences were because improvements such as the MOSES II land surface tile scheme were already operational in the Mes. The Mes version is summarised in the table below, where the physics schemes are drawn from a climate configuration of the model known as Hadam4. Several of the ND parametrizations were already operational in the Mes at the time of trialling, so the main differences were in the dynamical formulation.

New Dynamics	(Hadam4)Physics
Semi -Lagrangian advection (With monotone advection of potential temperature)	* Edwards-Slingo Radiation
Semi-implicit time integration	* Mixed phase precipitation • Including iterative freezing level
Horizontal staggering - C grid	* New Boundary Layer + 38L
Vertical Staggering - Charney Philips	* MOSES II land surface
Non-hydrostatic formulation	* Effective area cloud fraction Vertical gradient cloud fraction
	New physics compared to operational old dynamics
Lateral boundaries (4 point rim in trials, 8 point rim in operations)	Orography -smoothed (Raymond filter ε=1) • Lateral boundaries 6 global, 10 point linear transition to mesoscale orography
	Convection • CAPE closure, 30 min timescale • Momentum transport
	New Gravity wave drag
	Visibility in snow correction

*Already operational in Mesoscale Model.

The MOSES II land surface scheme has since been introduced operationally in the global model (December 2002). CAPE closure and convective momentum transport were part of the global ND change, as was the new gravity wave drag scheme. Gravity wave drag had not been used in the Mes before, but in separate tests it showed a beneficial impact on

Mes wind forecasts. The global and Mes ND versions are much more consistent than the operational models they replaced and this should lead to better coupling through the lateral boundaries.

The new model uses the same vertical grid as the global with the same placement of levels (Fig1.1). The levels are height, terrain following near the surface and constant above 17.5km.The transition to flat levels is rather quicker than the old dynamics (OD) levels which are pressure based, and levels are correspondingly thinner over high orography. Note that because of the staggering, the model has winds at 10m but not temperature and humidity which are vertically displaced to 20m for the first level (Fig 1.2). There are also slightly fewer levels in the first 2km than previously (10 cf 13 in OD), due to the generation of the grid by a smooth (quadratic) function, which is more accurate numerically.

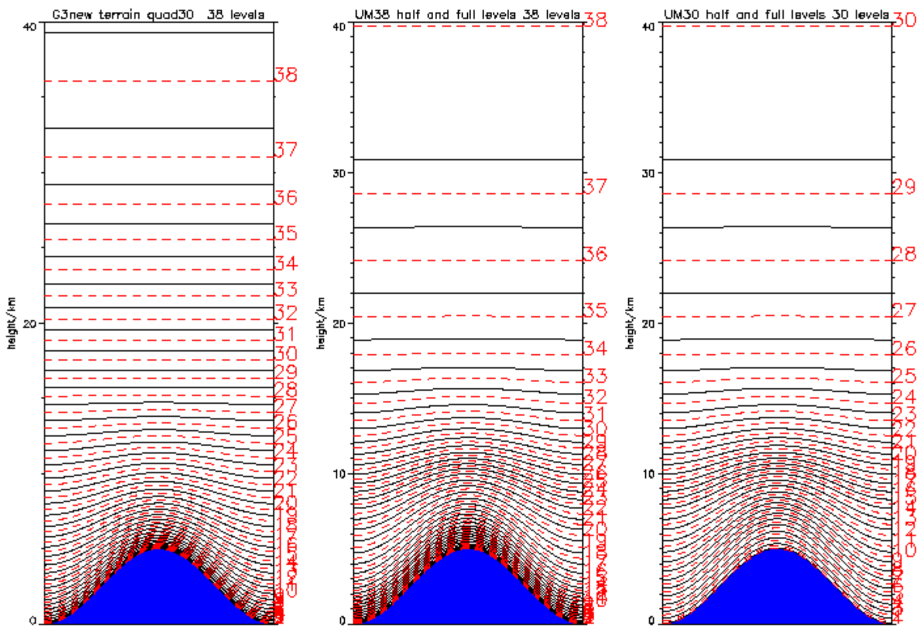


Figure 1.1 New Dynamics levels (left), old dynamics: mesoscale levels (centre) and global 30 levels (right)

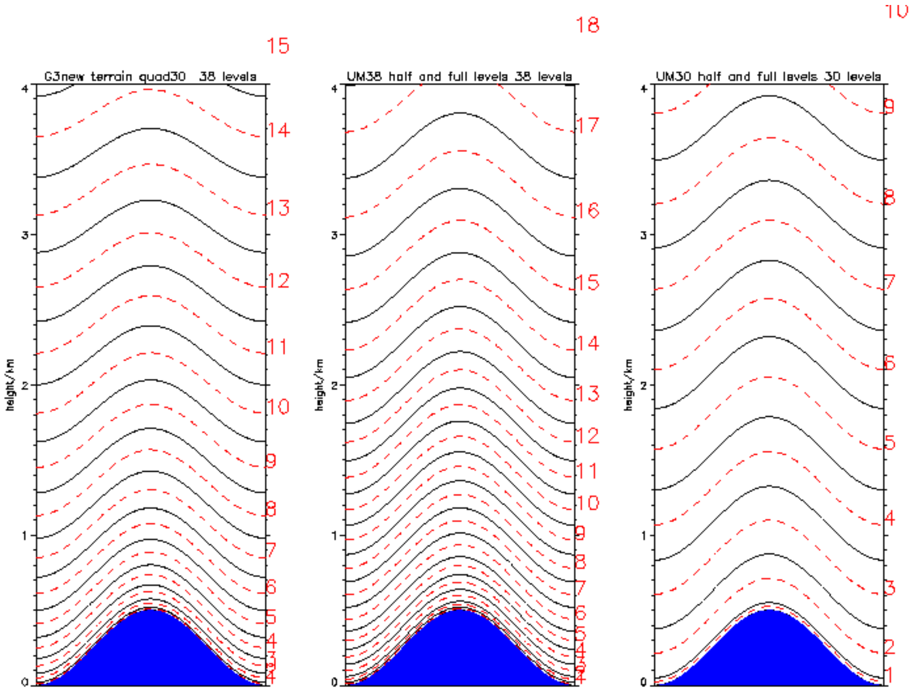


Figure 1.2 Levels location near surface: New Dynamics levels (left), old dynamics: mesoscale levels (centre) and global 30 levels (right)

1.1b Data Assimilation

The data assimilation system for Mes ND is almost the same as that for OD, described in Macpherson et al. (2002). New forecast error covariance statistics had to be derived because of the change in vertical grid. OD covariances came from several months of (t+24-t+12) forecast differences, covering both winter and summer. Those used in the ND tests described here were prepared from (t+24-t+12) forecast differences for a two-week period of shadow suite runs at the end of November and beginning of December 2001. This was recognised to be a very short period, a weakness to be addressed in future upgrades.

The horizontal length scales for the SOAR functions used to model forecast errors were maintained at their OD values: 130 km for streamfunction and unbalanced pressure, 180 km for velocity potential, and 90 km for relative humidity and log(aerosol). A scaling is applied to forecast error standard deviations to improve agreement between the covariances implied by the 3D-Var variable transforms and those 'observed' from the forecast differences. The initial ND scalings were maintained at their OD values of 2.2 for streamfunction, 0.6 for velocity potential and 1.3 for unbalanced pressure. It was recognised that these would need re-tuning in future.

One aspect which required some coding changes was the calculation of input terms to the Latent Heat Nudging (LHN) algorithm for rainfall assimilation. The LHN algorithm itself (Jones and Macpherson, 1997) is the same in ND but the model's large-scale latent heating rate needs to be computed in a different way for ND because of the different structure of the dynamics and physics routines within a model timestep. Increments from LHN (and from nudging towards cloud data) are regarded as 'part of the physics', so this part of the assimilation software, known as the AC scheme, is called at the end of the 'atmos_phys2' set of parametrization routines and before the Helmholtz equation solver at the end of the model timestep.

In more detail, we calculate the large-scale latent heating H from:

 H = T across large-scale precipitation routine +

 L/c_p { q_{CL} between end of advection and end of large-scale cloud routines)

where T is temperature, L is the latent heat of vaporisation, c_p the specific heat and q_{CL} the cloud liquid water.

The 'AC' assimilation code finishes with its own call to the large-scale cloud scheme to ensure that the temperature and moisture variables are in thermodynamic balance before the timestep continues.

A further small difference in the ND assimilation is that the analysis increments are calculated at full model resolution, rather than at half resolution as in operational OD.

1.2 The shadow suite

The 'real-time' parallel trial ran originally from 18th October 2001, but various technical problems and one or two bugs were encountered in the early weeks. Results were analysed only for the period since 6th December 2001.

In January 2002 it was discovered that the shadow suite had been rejecting screen temperature data from the assimilation - this was corrected on 16th January, and so separate analysis is included for the period before and after this change.

In late January, there was a problem in the global ND suite which resulted in significant loss of data to the global analysis. Mesoscale forecasts driven by global forecasts from this period have been omitted from the verification.

Two forecasts were run daily, from 00 and 12 UTC.

1.3 Case studies

Fifteen cases were chosen covering the required range of synoptic types (Table 1.1). Each was run with 12 hours of assimilation followed by a forecast to t+36.

Table 1.1: Case studies for Mes ND tests

DATE	DT	TYPE	WEATHER SUMMARY
18/05/00	00Z	Land Convection	**Thurs.18th**: Unstable NW'ly, with heavy showers becoming very widespread, and then thundery over eastern half p.m.
21/07/00	00Z	Clear Summer Day	**Fri.21st**: 1028 high covers UK, with little or no flow or cloud for most parts.
22/07/00	00Z	Widespread St & Sc	**Sat.22nd:** High pulling away to the north of Scotland, allowing stronger NE'ly flow over S Britain, with North Sea ST/SC spreading further inland. **Sun.23rd**: 1030 high centre now well north of Scotland, with low (1005) giving thundery rain as far north as mid Channel/S Devon Sunday night. Widespread ST/SC, except extreme N, W and S of Britain.
16/08/00	12Z	Unstable, Showers	**Wed.16th**: Complex low (1003) pressure region NW and N of U.K. giving an unstable SW'ly over all parts, with showers, especially in W and N.
18/08/00	12Z	Organized Convection (Summer)	**Fri.18th**: Shallow (1008, but slowly deepening) low and assoc. fronts moving NE across S England, with patchy heavy rain. **Sat.19th:** Weak but unstable NW'ly flow over most parts as low centre deepens further but drifts away over the North Sea.
23/09/00	00Z	Late Summer Day	**Sat.23rd**: 996 low off W Ireland and a large 1037 high over E Europe giving a brisk but warm SE'ly.
27/09/00	00Z	Active Fronts	**Wed.27th**: ~970hPa Atlantic low pushing occluding front quickly east across U.K.
29/10/00	12Z	Fronts & Land Gales (30th of October Storm)	**Sun.29th**: Open wave runner moving rapidly ENE, bringing heavy rain to most of England and Wales by late afternoon. Second baroclinic feature developing much more, down to 976 over SE Ireland by the end of the day and so close to the first one as to keep the rain going continuously over parts of the south all night. **Mon.30th**: Low further deepening to 958hPa near Manchester by 6a.m. and 948 off Lincs. coast by midday. Deepest later in the day of 941hPa over the N Sea. Cold front clearing SE England midmorning, with strongest gusts near this. Max. gust of 61kn (70mph) at Odiham between 6 and 7 a.m. 35-40mm locally in the period 3p.m. Sunday to 8a.m. Monday, leading to the worst flooding for between 10 and 32 years on local rivers on Monday and Tuesday. First snow over higher parts of N England on western side of low.
02/11/00	00Z	Organized Convection (Winter)	**Thurs.2nd**: Larger, more uniform rain area developing over S and SW in assoc. with (developing comma cloud) cold air low of 978 moving E across Ireland in the early morning and then continuing across N Wales to NE England and further deepening to 971 off Lincs. coast by the end of the day. Scattered showers in generally unstable flow to rear of PVA max.
14/11/00	12Z	Radiation Fog	**Tues.14th**: Very slack flow developing, with showers restricted to coastal areas later. **Wed.15th**: Early fog quite widespread and persistent over cent.

			S England, Midlands and E Anglia. Increasing gradients associated with approaching occluding front helping to clear the fog from most parts early p.m. (later in E Anglia).
27/12/00	12Z	Organized Convection (Winter) Mixed Snow and Rain	Wed.27th: Cold air feature (988 low) and assoc. occluded/cold front sweeping SE, with mostly snow associated with narrow but quite intense frontal band into western parts by the end of the day.
13/01/01	00Z	Clear Winter Night	Sat.13th: 1036 high over N Sea further intensifying to 1041, keeping fairly brisk E'ly in south and calmer, sometimes foggy conditions further north. Sun.14th: High centre transferring slowly ESE to Continental Europe.
18/01/01	00Z	Stratocu	Thurs.18th: Light E to SE'ly continues over all parts. Widespread SC, and thick enough in places for a few snow flurries. Cloud amount underdone by the Mesoscale.
20/01/01	12Z	Mixed Snow and Rain Warm Advection	Sat.20th: Weak, slightly ridged S to SE'ly hanging on in east, more brisk S'ly developing in the west. Sun.21st: Block breaking down, with occluding front crossing all except the extreme east by the end of the day, introducing a milder S'ly. Much of the ppn. falling generally as sleet over inland southern areas and snow from Midlands northwards.
16/02/01	12Z	Fog and st (small areas)	Fri.16th: 1038 high centre persisting over Ireland, with weak cold front continuing slowly SE'wards. Sat.17th: 1044 High centred on U.K. Many parts sunny, fog persisting in a few places (S Midlands/Cheshire plain).

2. Subjective assessment

The output fields compared were: precipitation, pmsl, high, medium and low cloud, 1.5 metre temperature, fog probability, all on 3-hourly frames and compared against actual surface observations (plotted charts) and archived rainfall radar pictures. Only those fields and times where significant differences were seen between ND and Control (OD) are noted below.

2.1 Case studies

Clear summer day

1.5m temperatures around 1 deg. C. lower (worse) during the daytime in the ND run over large areas of central and southern England. Figure 2.1 shows this difference at T+15.

Land-based convection

No significant differences.

Organised convection (winter)

On the T+36 pmsl frame, ND 30 nautical miles worse position for a low centre over the central North Sea, but 2hPa better in depth.

Clear winter night

No significant differences.

Radiation fog

1.5m temperatures higher (better) over parts of Scotland at T+15 and T+18. Also, on some later frames fog probability was higher (better) over eastern England.

Unstable, showery

No significant differences.

Summer time frontal system

ND better at handling North Sea low on later frames and also better for having less fog at T+12, 15 and 18.

Mixed snow and rain

ND pmsl better on later frames with trough over eastern England. Fog probabilities also better on most frames in ND run.

Widespread low cloud

T+15 and T+18 ND frames better for 1.5 metre temperature.

Weak wintertime cold front

ND worse for fog probability at T+24 and T+27 for holding onto too much fog over Ireland. See figure 2.2.

Stratocumulus

ND run preferred for having more low cloud over central and southern parts of England from T+12 to T+24. See Figure 2.3 for the difference at T+18. For 1.5 metre temperature however the ND run was 1 to 3 deg. C. colder over parts of the U.K. and Continent from T+6 to T+15, and the control run was preferred.

Late summer day

ND better for having rain-band around 3 hours faster on later frames, as seen in Figure 2.4.

Active fronts

No significant differences.

Organised convection with mixed snow and rain
No significant differences.

Active fronts and land gales
Slight preference for Control pmsl throughout. Figure 2.5 shows the small differences in pmsl between the two runs, with the ND run a little faster with the secondary, developing low centre approaching South Wales. ND preferred for having less low layered cloud on later frames in an unstable westerly airstream.

General differences
Fog probabilities in precipitation are lower in the ND runs over higher model orography, and 1.5 metre temperatures are up to 4 deg. C. different over the highest orography (Alps and Norway). Both these changes are thought to be due to the differences in model orography itself e.g. 'smoothed orography' is used in ND. Convective rain has different characteristics in the ND runs as a result of Cape Closure being used. The main effect of this is to cause convective rainfall to be of a more uniform rate than seen in operational OD output over quite large areas. Pmsl in some ND runs was found to be rather noisy, especially on and near the Mes domain boundaries in strong flow. (A correction for this was tested later - see section 4). Also, in several ND runs pmsl was found to be around 1hPa lower (slightly worse) generally over some parts of the U.K.

The overall assessment of the case studies is given in the table.

Control preferred	New Dynamics preferred	Neutral overall
4	4	7

2.2 Shadow Suite

A number of ND and operational runs were compared on a daily basis and a very similar signal of neutrality was seen as in the case studies. The problem with noisy pmsl in the ND runs was again obvious. Some ND runs appeared to have a 1 or 2 degree C. cold bias on some frames of a few forecasts.

Summary of subjective verification
A broadly neutral picture was seen in the subjective assessment of both the case studies and parallel suite output, with the ND runs slightly favoured, mainly for the improved handling in some situations of precipitation, low cloud and fog probability.

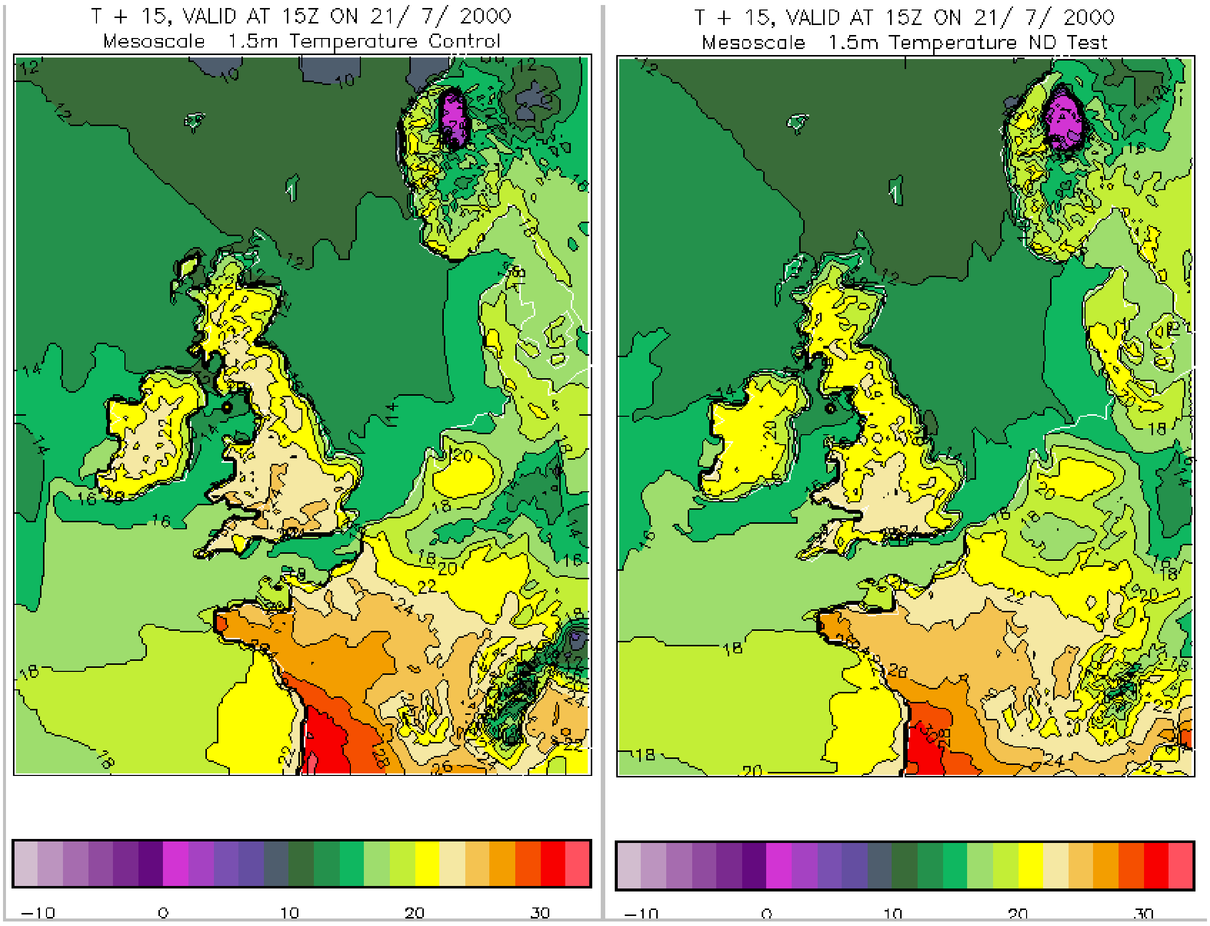
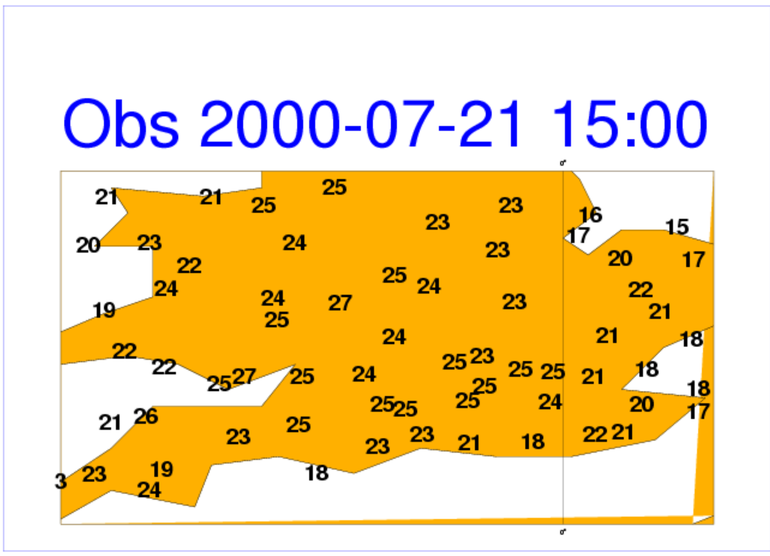


Figure 2.1: T+15 screen temperature valid at 15 UTC, 21/7/2000. Control (left frame) and ND trial (right frame). Temperatures are around 1 deg. C. lower (worse) during the daytime in the ND run over large areas of central and southern England.

Figure 2.1a: Observed temperatures



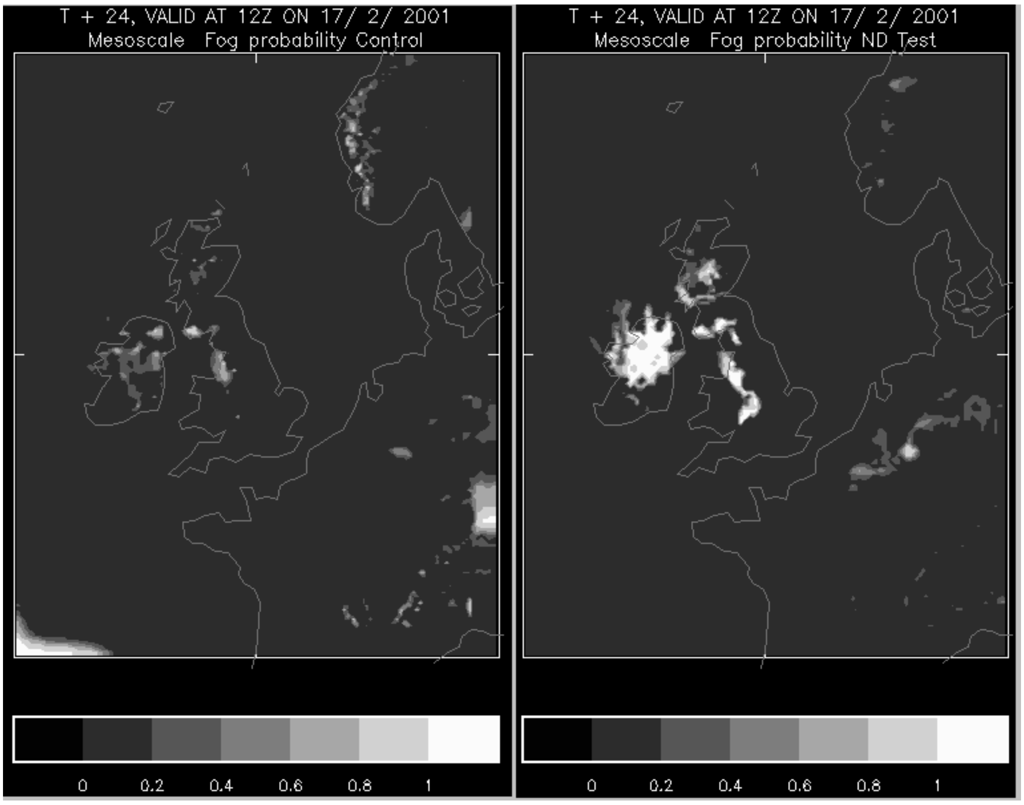


Figure 2.2: T+24 fog probability valid at 12 UTC, 17/2/01. Control (left frame), ND trial (right frame). ND is worse for holding onto too much fog over Ireland.

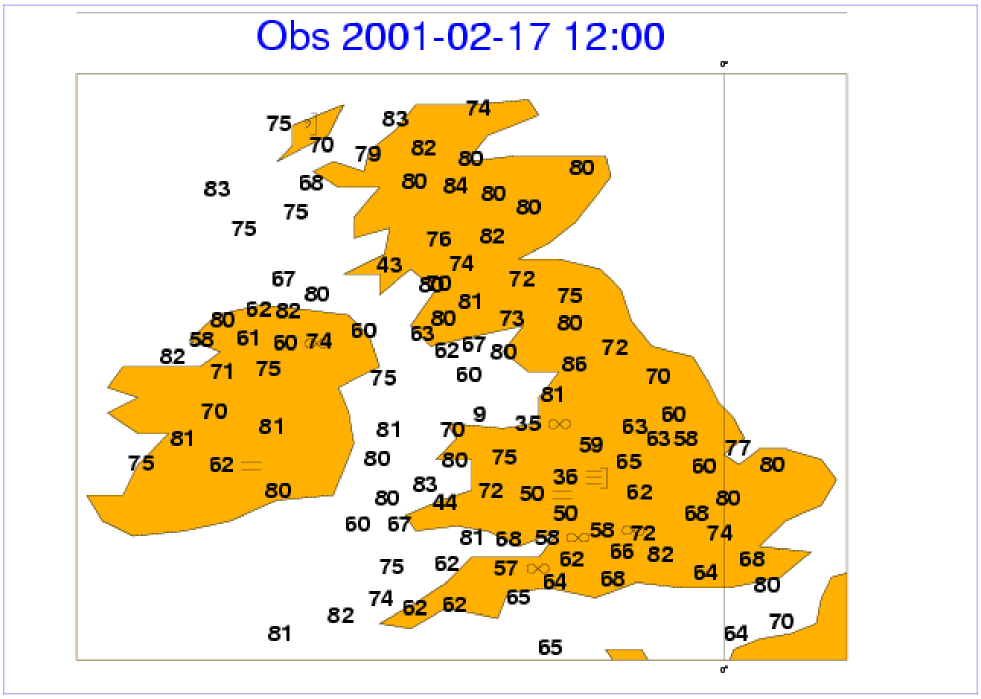


Figure 2.2a Observed visibility and weather

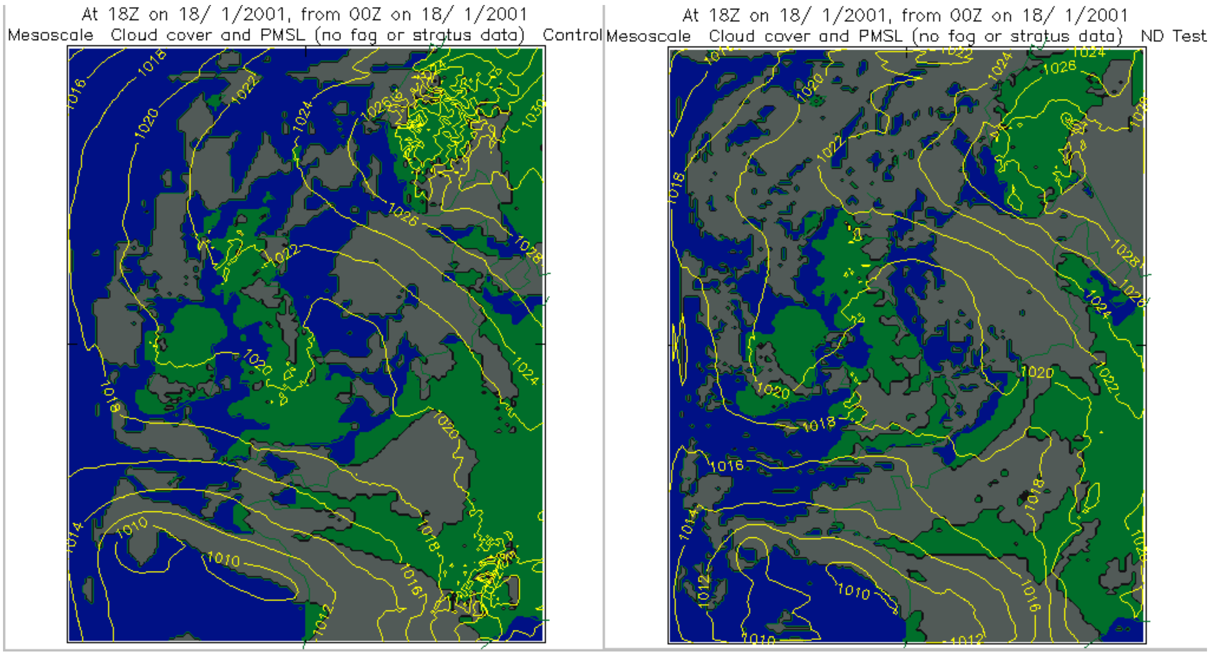


Figure 2.3: T+18 cloud cover (and pmsl) valid at 18 UTC on 18/1/01. Control (left frame) and ND trial (right frame). ND run preferred for having more low cloud over central and southern parts of England.

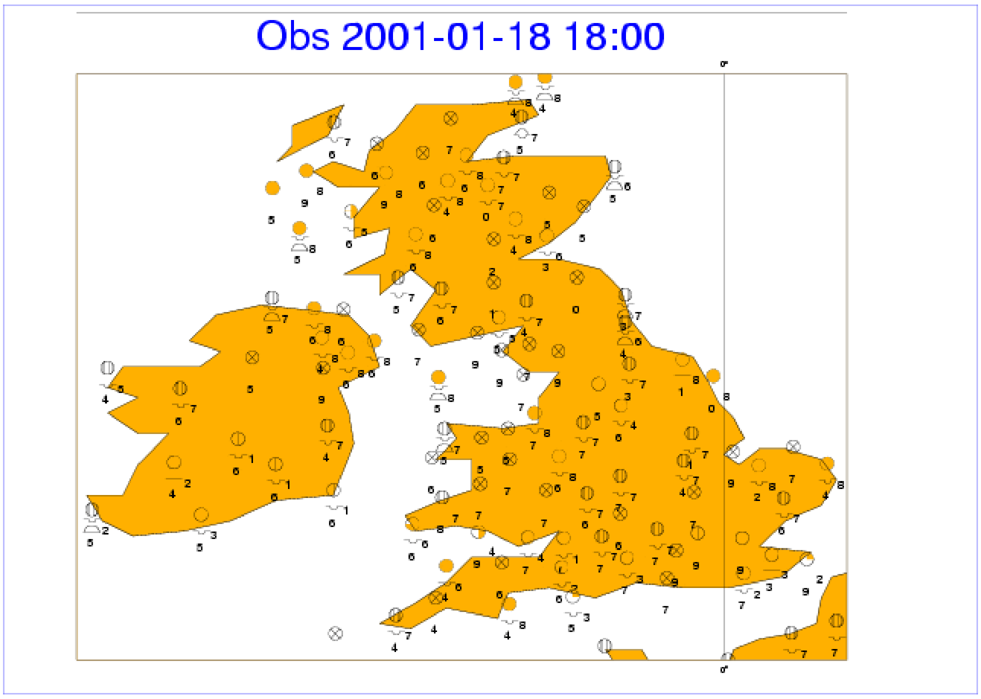


Figure 2.3a Observed cloud

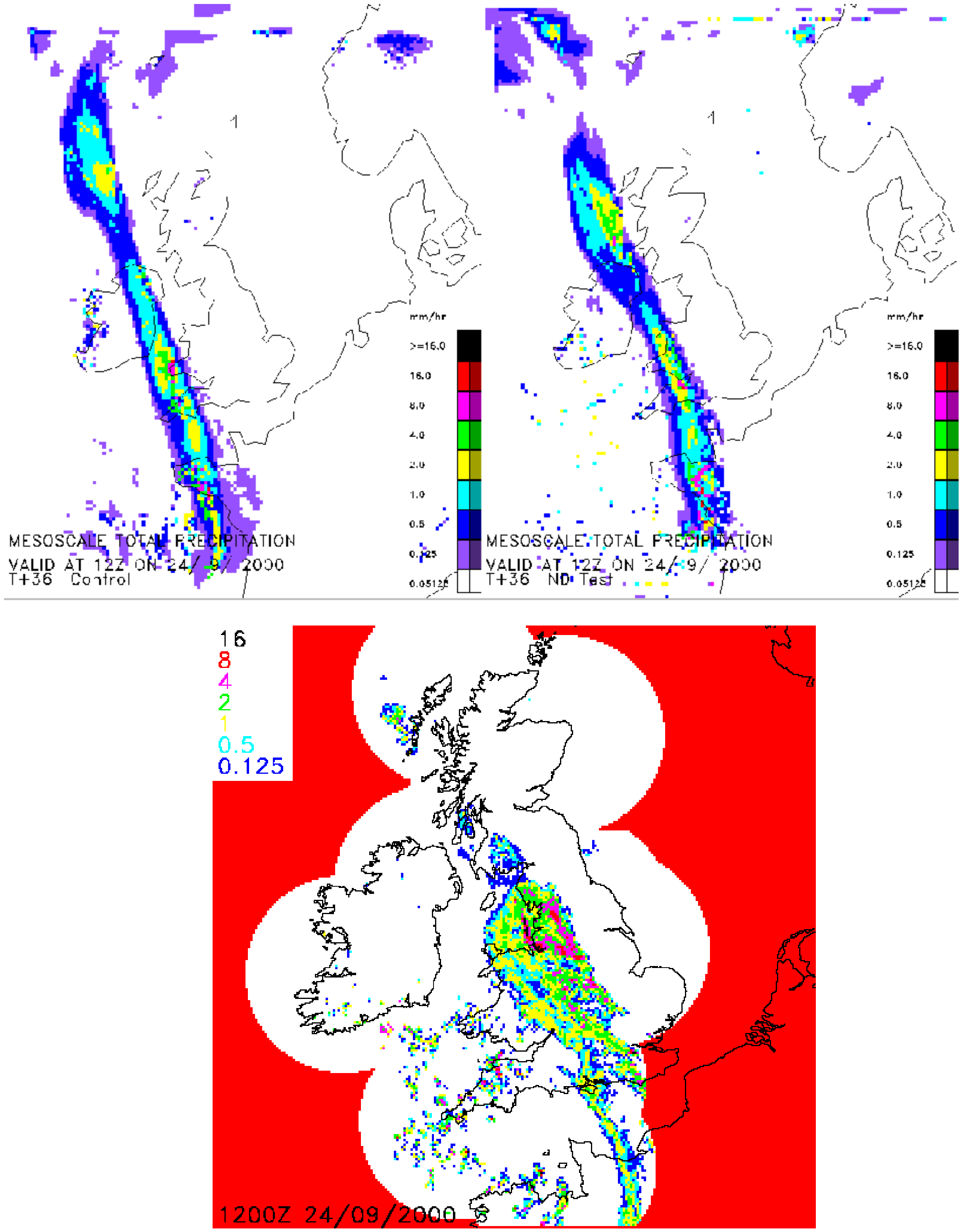


Figure 2.4: T+36 rain rate forecasts valid at 12 UTC, 24/9/2000. Control (top left frame) and ND trial (top right frame). Verifying radar composite (bottom frame). ND is better for having the rain-band around 3 hours faster.

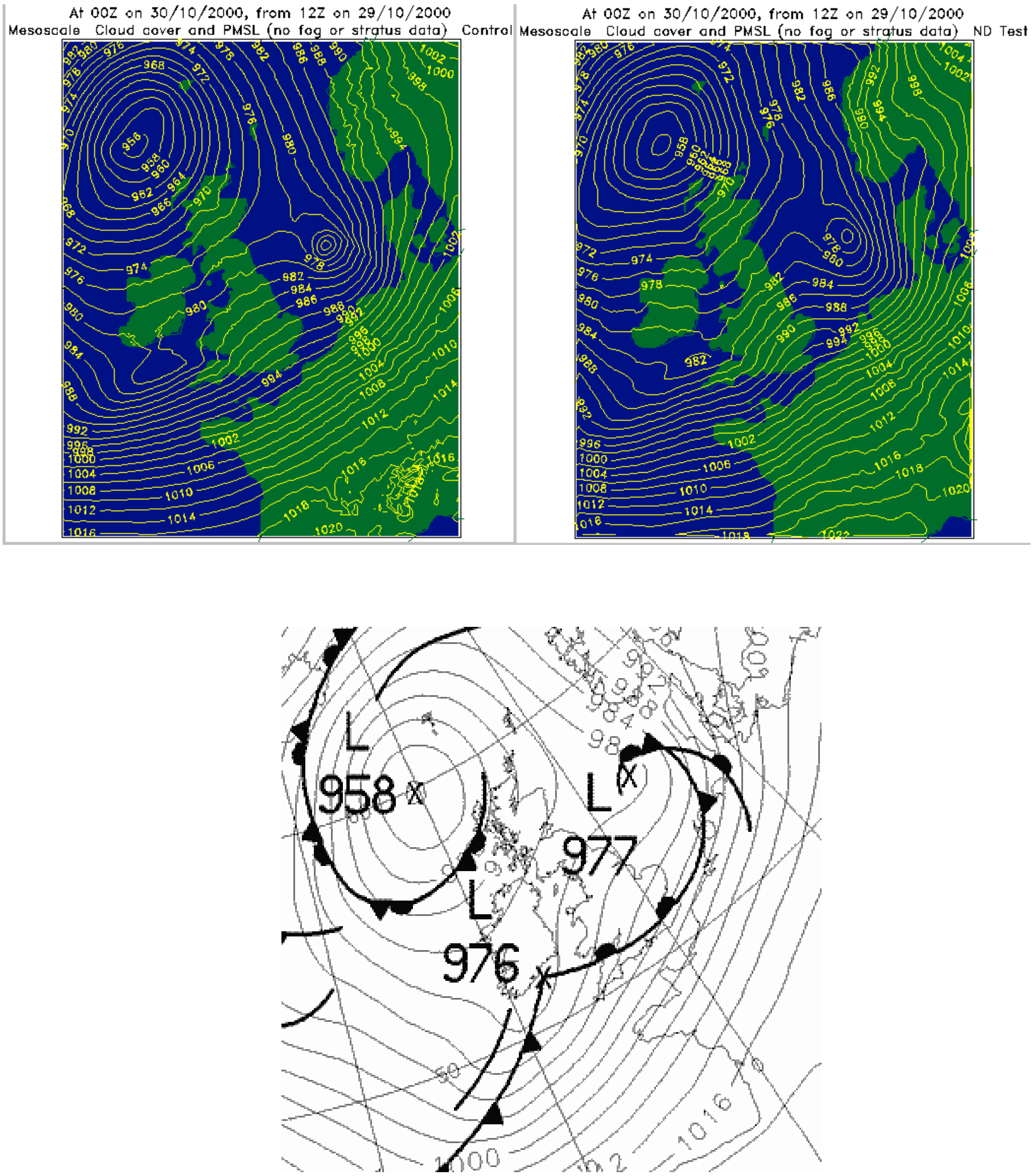


Figure 2.5: T+12 pmsl valid at 00 UTC, 30/10/2000. Control (top left frame) and ND trial (top right frame). Verifying analysis (bottom frame). The ND run is a little faster with the secondary, developing low centre approaching South Wales. Control slightly preferred.

3. Objective Verification

3.1 Case Studies

The variables making up the 5-component UK index were verified and the results presented in Table 3.1 are averaged over all cases and forecast times from t+6 to t+24, as used in the index. The station list used is 'all UK stations', which provides better sampling than the standard UK index list of only ~40 stations.

Variable	Control		Trial		Change in Skill/ETS
	rms	ETS/skill	rms	ETS/skill	
10-metre wind	2.81	0.750	2.89	0.737	-0.013
screen temperature	1.67	0.650	1.64	0.662	+0.012
precipitation		0.343		0.335	-0.008
cloud amount		0.219		0.219	0.000
visibility		0.139		0.173	+0.034
average 'UK index'		0.4202		0.4253	
		%age change in UK index for trial			+1.2%

Table 3.1 - Summary of UK index components for the case studies

Skill changes for *10-metre wind and screen temperature* were estimated on the basis of mean skill in the control being 0.75 for wind and 0.65 for temperature. They showed a slight improvement for temperature and a slight degradation for wind. This trend was also reflected in the results averaged over all stations in the model area.

For *precipitation*, the verification is against 6-hourly accumulations at surface stations. The scores were derived from all 15 cases for most forecast times, but verification data at t+6 were available for only 4 cases. This smaller sample at t+6 was taken into account in the calculation of the average ETS over all forecast times. The slight detriment in the overall trial ETS is more noticeable for light rain than for heavy rain. The trial detriment is slightly smaller for UK stations than for the whole model area, though this may not be a statistically stable result.

For cloud cover, the trial showed a neutral result at UK stations, but an improvement for all stations in the model area which was evident at nearly all forecast times and thresholds.

For *visibility*, the trial gave a significant improvement, both at UK stations and over the whole area. The biggest improvement was apparent at the lowest, 200-metre threshold, for which the sample of events is small. However, this improvement was also marked in the first phase of the shadow suite when the incidence of fog was relatively high.

Summary

Table 3.1 shows an estimated UK Index impact of +1.2%, while the comparable figure from verification over the whole model area is +2.2%. A very modest overall advantage to the trial is implied.

3.2 Shadow suite

Results for the 5-component UK index are presented first for all available runs over the period 16th January - 6th February, after the screen temperature problem was fixed. Results are averaged over forecast times from t+6 to t+24 as used in the index, with a station list of 'all UK stations', and summarised in Table 3.2. The sample size is 32 forecasts.

Variable	Control		Trial		Change in Skill/ETS
	skill	ETS	skill	ETS	
10-metre wind		0.783		0.793	+0.010
screen temperature	0.877		0.886		+0.009
precipitation		0.322		0.320	-0.002
cloud amount		0.295		0.286	-0.009
visibility		0.047		0.045	-0.002
average UK index		0.465		0.466	
		%age change in UK index for trial			+0.3%

Table 3.2 - Summary of UK index components for the shadow suite (*after* 16th January 2002)

For *screen temperature* and *10-metre wind*, the trial showed a slight improvement, while for other variables, a slight detriment, leading to an overall +0.3% improvement. The corresponding overall UK index shift for stations over the whole model area is a +1.9% improvement. These figures are not inconsistent with a neutral signal.

Although not part of the UK index, *relative humidity* showed a significant improvement in the trial, with a reduction in bias from around 4% to approximately zero, along with a lower rms error (Figure 3.1). This change in humidity bias goes along with a warming of ~0.2-0.3K in the trial (Figure 3.2) and lower rms temperature errors.

The *cloud cover* bias in the trial analysis was reduced by ~0.3okta, and the spinup of cloud cover in the first 6 hours of the forecast was smaller by ~0.4okta (Figure 3.3). It is not clear what the reason for this improvement in the analysis may be, but the new consistency between global and mesoscale microphysics parametrization in ND may be contributing, as may the better match between ND model levels and analysis levels in 3DVar.

Results were also computed for the 41-day period prior to the screen temperature correction being introduced (Table 3.3). The sample size is 59 forecasts. The lack of screen temperature data was certainly a disadvantage to the trial, yet it still showed a +1.3% improvement overall at UK stations (+2.9% for stations over the whole model area).

A significant part of the improvement came from the visibility component in what was a relatively foggy spell. The improvement in ETS at the 200m threshold is associated with an increase in the trial frequency bias from 1.0 to 1.7, while at the 1000m threshold the trial bias is only 10% higher. This period is a more reliable guide to the impact of the trial on visibility than the post-16th January mobile spell with very few fog events.

Variable	Control		Trial		Change in Skill/ETS
	skill	ETS	skill	ETS	
10-metre wind		0.671		0.676	+0.005
screen temperature	0.749		0.748		-0.001
precipitation		0.248		0.236	-0.012
cloud amount		0.302		0.309	+0.007
visibility		0.205		0.234	+0.029
average UK index		0.435		0.441	
		%age change in UK index for trial			+1.3%

Table 3.3 - Summary of UK index components for the shadow suite (*before* 16th January 2002)

When the two periods before and after the 16th January are combined (up to 4th February), the UK index estimate for the UK area is an improvement of +1.5%, while that for the whole area is +2.8%. It is at first surprising that these figures do not show smaller improvements than those for the period before 16th January. The result is a consequence of the different event frequencies in the different periods and their relative contribution to a combined contingency table for the whole period, together with the nonlinear properties of the skill scores.

PMSL verified worse in the trial, at least in the first 12-18 hours (Figure 3.4a), though rms errors were some 20% larger throughout in the period before 16th January (Figure 3.4b) when the type was more anticyclonic. These problems were almost certainly due largely to a boundary updating problem which generates the gravity waves and noise seen in the subjective assessment. There is little evidence of any worsening in synoptic terms. See Section 4 below for a solution to this problem.

3.2.1 Rainfall verification against Nimrod

For *precipitation*, verification was also derived from comparison of the model accumulations with those from radar-based analyses produced by the Nimrod nowcasting system. This form of verification has been used for a number of previous Mes trials and benefits from the greater representivity of the radar coverage compared to the surface observing network. It is also more consistent with the usual method of subjective assessment.

The verification was done at four times model resolution, i.e. 6-hourly accumulations over $(48km)^2$ were compared. It is worth noting that since only 2 forecasts per day were verified, this leads to different observational samples at different forecast ranges, which contributes to the non-monotonic behaviour of the skill measures with forecast range.

Furthermore, two thirds of the period from 6th December to 28th January had only little rain. Various skill scores are plotted in Figure 3.5.

There is a 5-10% higher positive frequency bias in the trial than in the operational model, except for heavy rain which was generally forecast 60-100% too often. This higher bias generally translates into a higher hit rate and higher false alarm rate. The net effect is a slight decrease in the skill scores in the trial for light and moderate rain and almost no change for heavy rain. The deterioration of the scores is most marked at early forecast ranges (in particular T+6). At longer ranges (>T+24) the model performances are very similar. There are only minor differences when verifying over different areas (not shown; whole British Isles-radar area, UK-land radar area only, whole radar area (including France)).

The overall impact of the trial on the ETS score is negative, consistent with the verification against station data in Tables 3.2 and 3.3, though the Nimrod figures imply around twice the detriment. When Nimrod scores are substituted for station scores in the UK index estimates for the whole period of the trial, this takes ~0.6% off the overall UK index improvements of 1.5% (UK area) and 2.8% (whole area) noted above.

3.2.2 Later results from extended shadow suite

Although the period from 6th December – 6th February was the main one used for assessment, the shadow suite was run up to operational implementation in early August. Objective verification was summarised by the increment to the UK index in each month, giving the following results:

	UK Index increment (%)	
	UK area	whole model area
Dec6th-Feb6th	+1.5	+2.8
March	-1.7	+0.8
April	-1.4	-0.5
May	-0.1	+0.7
June	-1.6	-0.4
July	-3.1	-2.7

from which we see that performance was less encouraging in the later months, although scores for the whole model were better than for the UK alone.

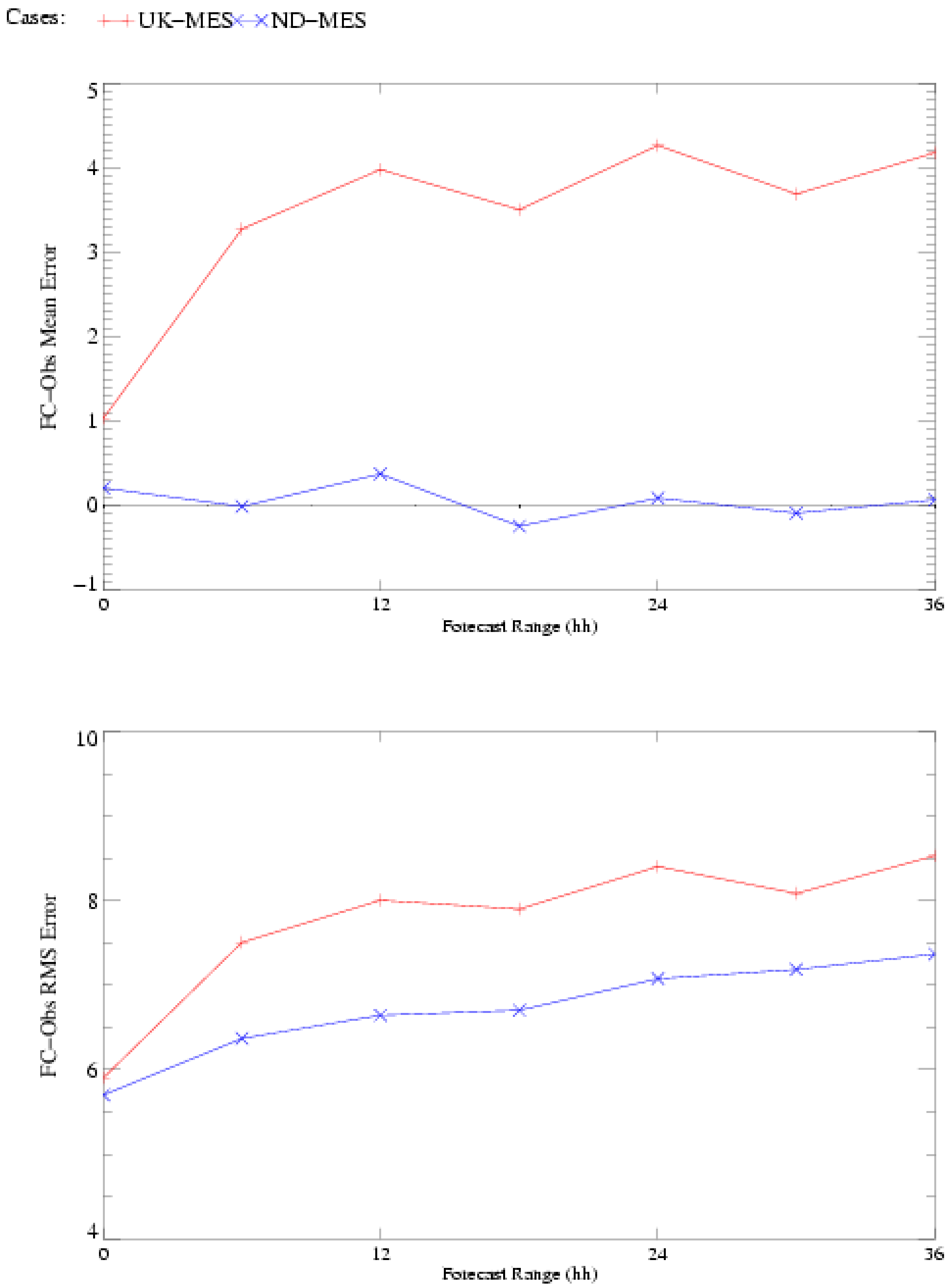


Figure 3.1: Screen relative humidity verification as a function of forecast range in shadow suite from 16th January-4th February 2002. Operational in red, New Dynamics in blue. Top panel for mean error, lower panel for rms error. Verification is at all stations in model area.

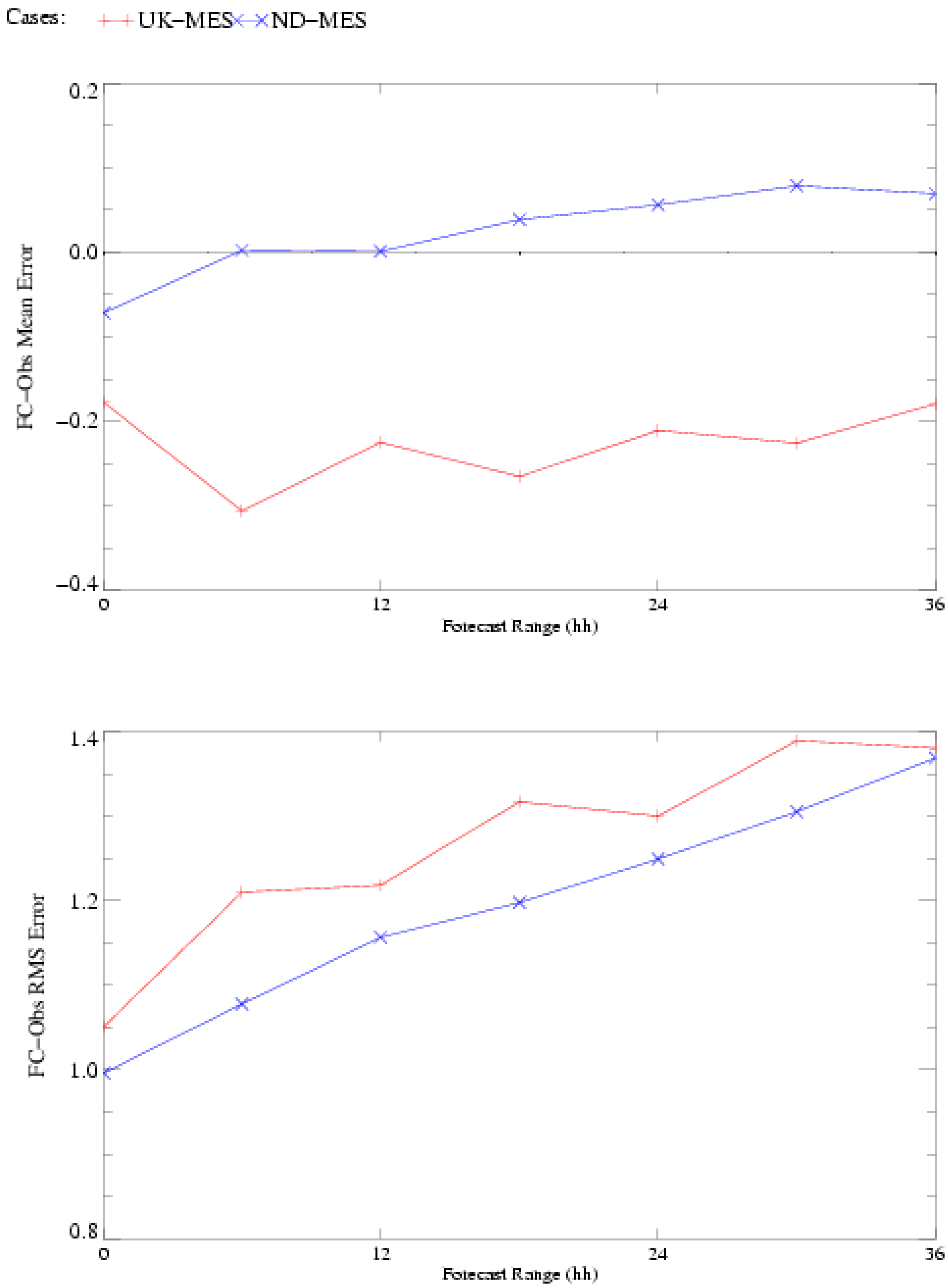


Figure 3.2: Screen temperature verification as a function of forecast range in shadow suite from 16th January-4th February 2002. Operational in red, New Dynamics in blue. Top panel for mean error, lower panel for rms error. Verification is at all stations in model area.

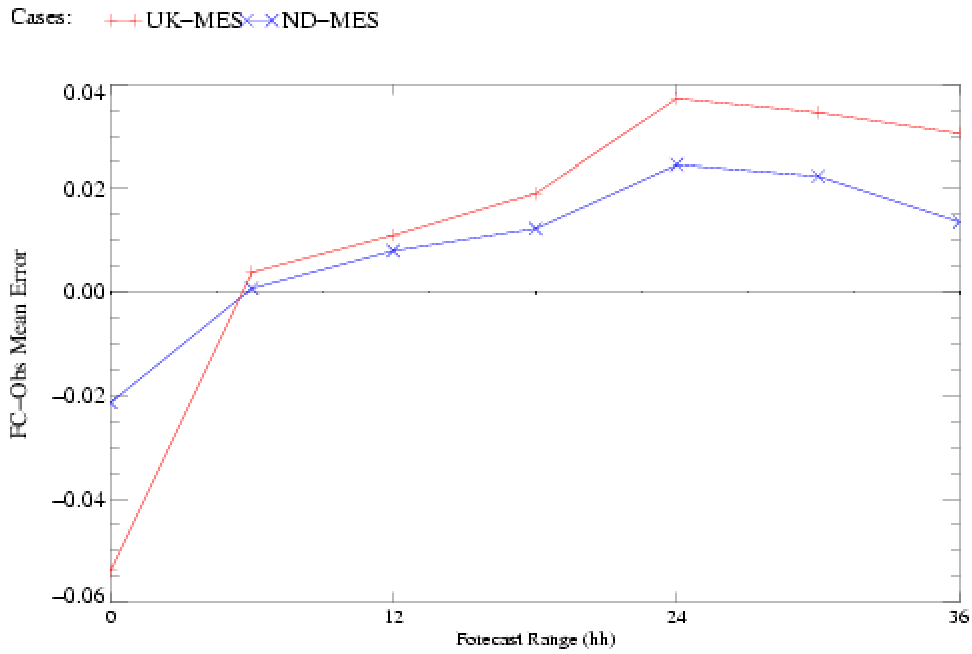


Figure 3.3: Mean fractional error in total cloud cover as a function of forecast range in shadow suite from 16th January-4th February 2002. Operational in red, New Dynamics in blue. Verification is at all stations in UK area.

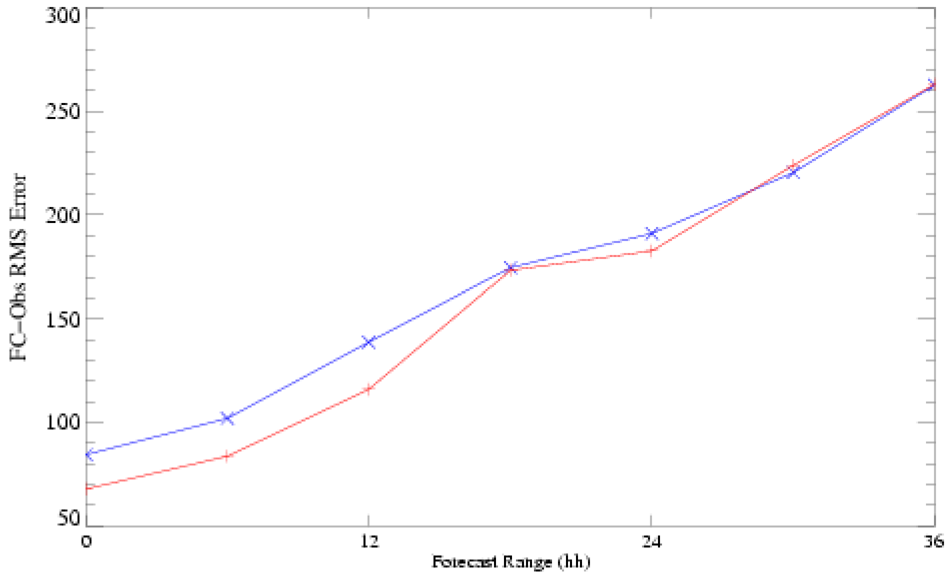


Figure 3.4a: Rms error (Pa) in PMSL as a function of forecast range in shadow suite from *16th January-4th February 2002*. Operational in red, New Dynamics in blue. Verification is at all stations in UK area.

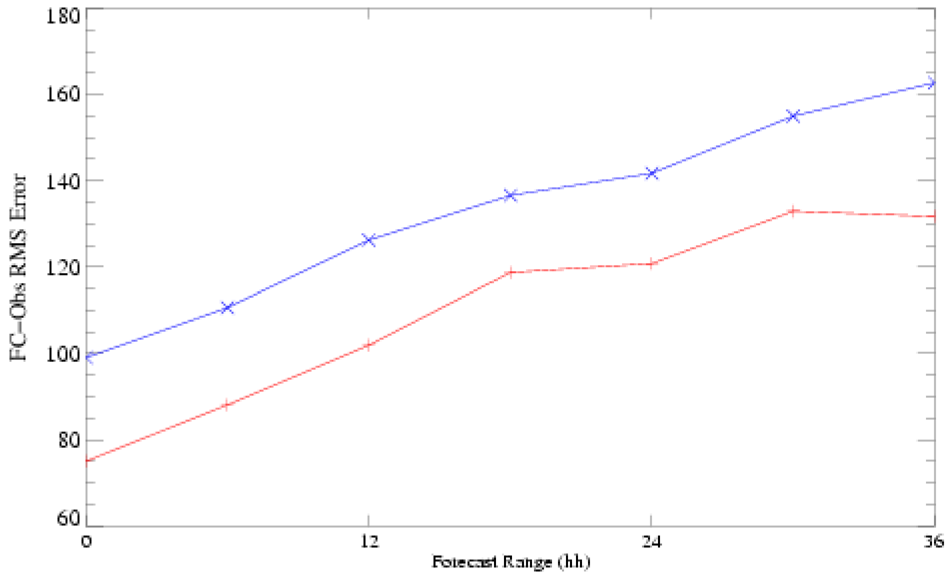


Figure 3.4b: Rms error (Pa) in PMSL as a function of forecast range in shadow suite from *6th December 2001-15th January 2002*. Operational in red, New Dynamics in blue. Verification is at all stations in UK area.

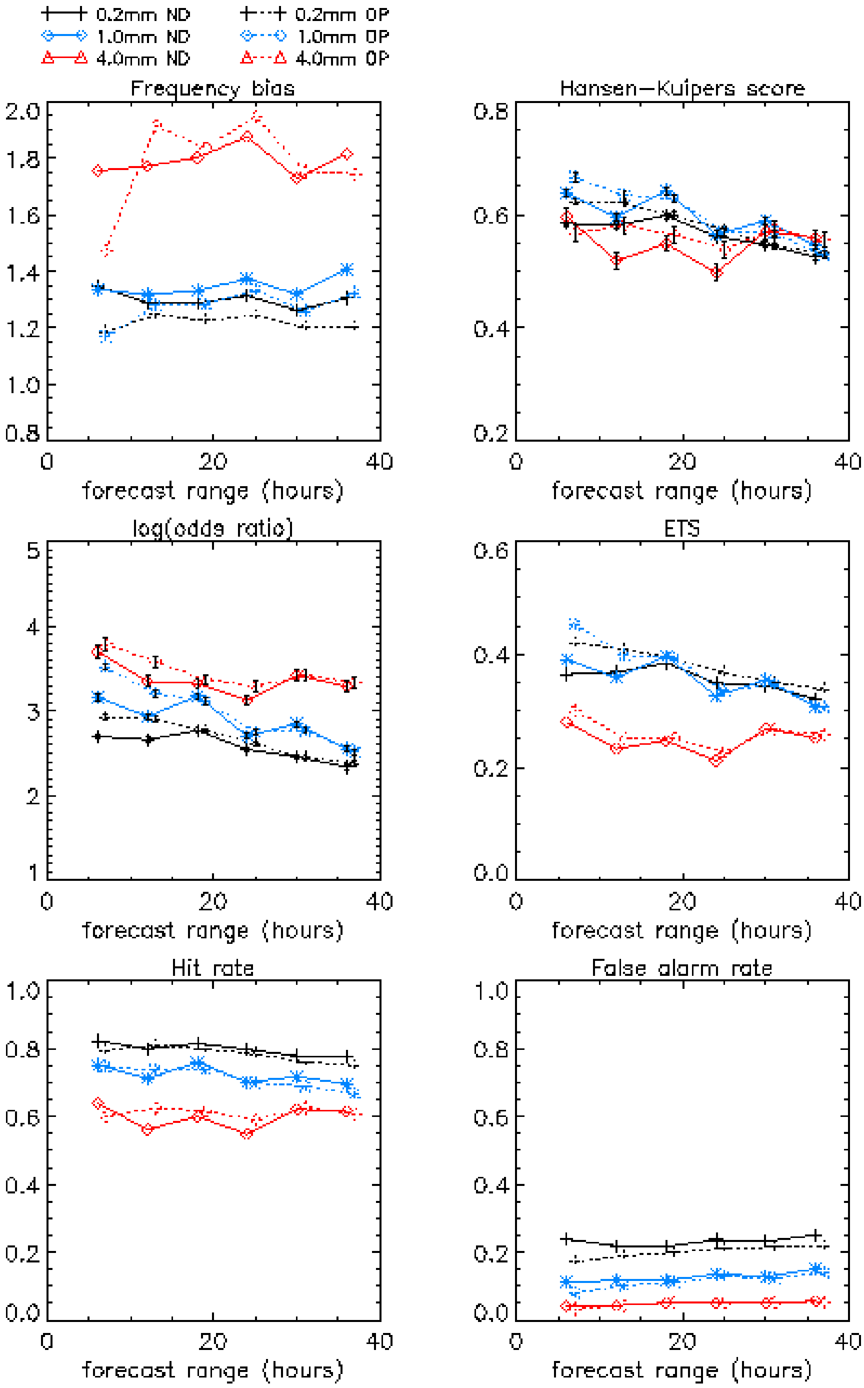


Figure 3.5 Categorical statistics of trial (ND, solid line) and operational model (OP, dotted line) 00,12Z-forecasts, 6/12/2001-28/1/2002. OP curves have been shifted by 1-hour to prevent overplotting of the 90% confidence intervals for Hansen-Kuipers score and log(odds ratio). Colours vary according to rainfall threshold as indicated in the key.

4. Boundary updating problem

Objective verification of Mes ND pmsl showed it could be 10-20% worse than the OD control. Looking at individual cases (especially when run as animations) revealed much variation in the pmsl field from hour to hour. Small scale waves were propagating in from the boundaries creating a ridge-trough-ridge 'sloshing' effect. Also, there were still significant 'kinks' at the boundaries where the boundary solution was not in agreement with the internal Mes solution.

Modifications to the treatment of the lateral boundary conditions (lbcs) were tested to improve the pmsl fields. The 4 point rim was expanded to 8 points, with weights for the global model contribution (from the lbcs) of (1,1,1,1,1, 0.75, 0.5, 0.25). This allows a proper calculation of the semi-lagrangian advection to be done since there is full model information in the outermost 5 points of the rim. (Subtle coding changes to the model are needed to make the 4 point rim calculations correct.) The impact of the 8 point rim is shown in Figure 4.1. The field is continuous and smooth at the outer boundary and the gravity waves that progress through the domain with a 4 point rim are largely absent.

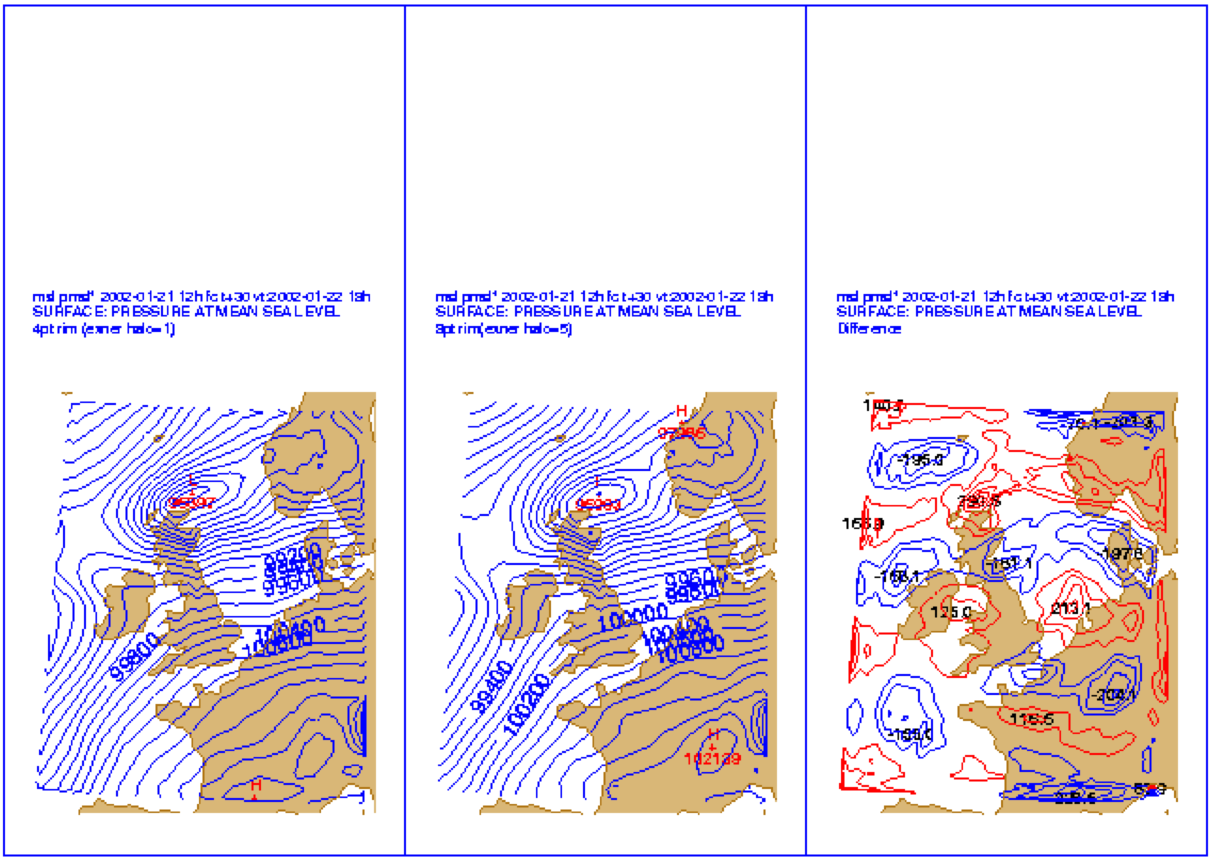


Figure 4.1 t+30h forecasts 4point rim (left), 8 point rim (centre) and difference (right)

Verification of 3 cases showed that the rms errors were much reduced up to 10%. (Figure 4.2). The early t+6 score is worse but this is attributed to the data assimilation not being redone with the 8 point rim. The 10m winds verification (Figure 4.3) shows mostly small improvements (less than 0.5%).

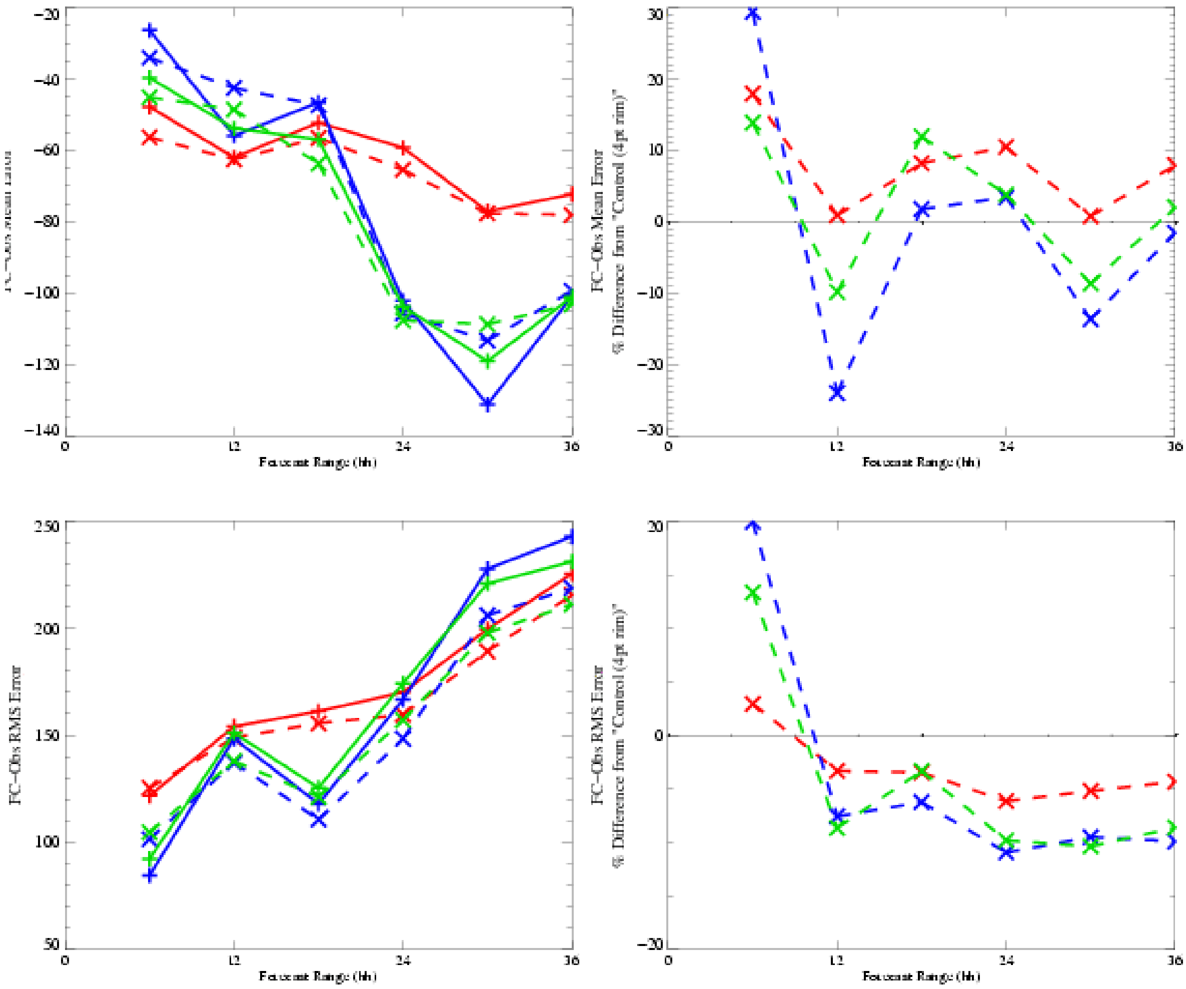


Figure 4.2 PMSL verification for 8 point rim versus 4 point rim; bias (top), rms (bottom)., % changes shown in right column for UK list (green), "All UK" (blue) and full model area (red)

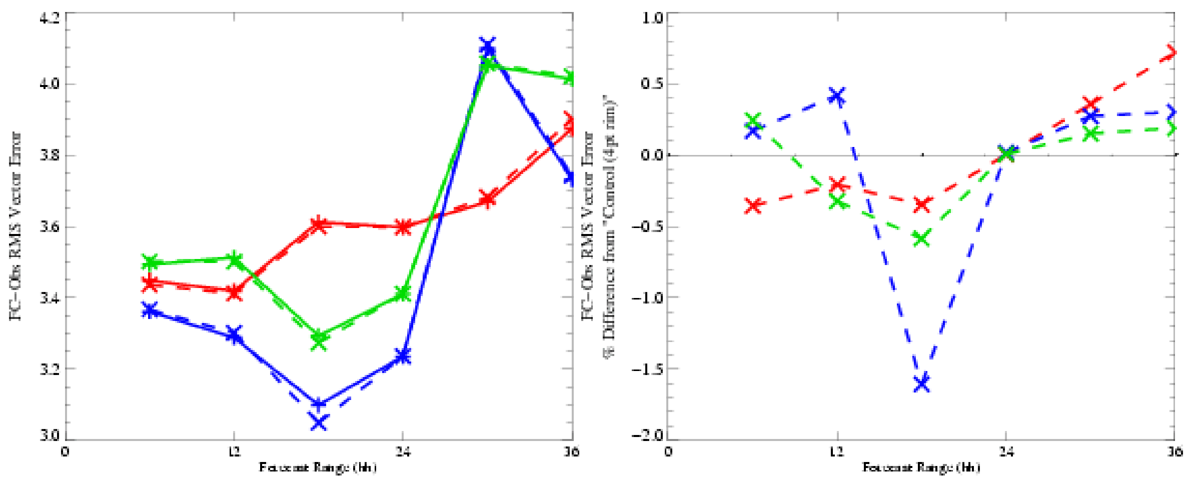


Figure 4.3 10m wind verification for 8 point rim versus 4 point rim; rms vector errors (left) and % changes (right) for UK list (green), "All UK" (blue) and full area (red)

5. Convection cases

A number of operational convection problems were noted during the summer of 2001. These sometimes resulted in unrealistic mesoscale convective precipitation rings, which developed and expanded as the grid scale gust front evolved out from the initial convective cell. To see whether these would affect the ND in the same way, the cases were rerun from interpolated operational analyses.

The ND runs were much better than the operational OD controls (see Figures 5.1 and 5.2), with much more realistic convective rain patterns. No signs of grid point storms were evident in all the reruns done for these cases.

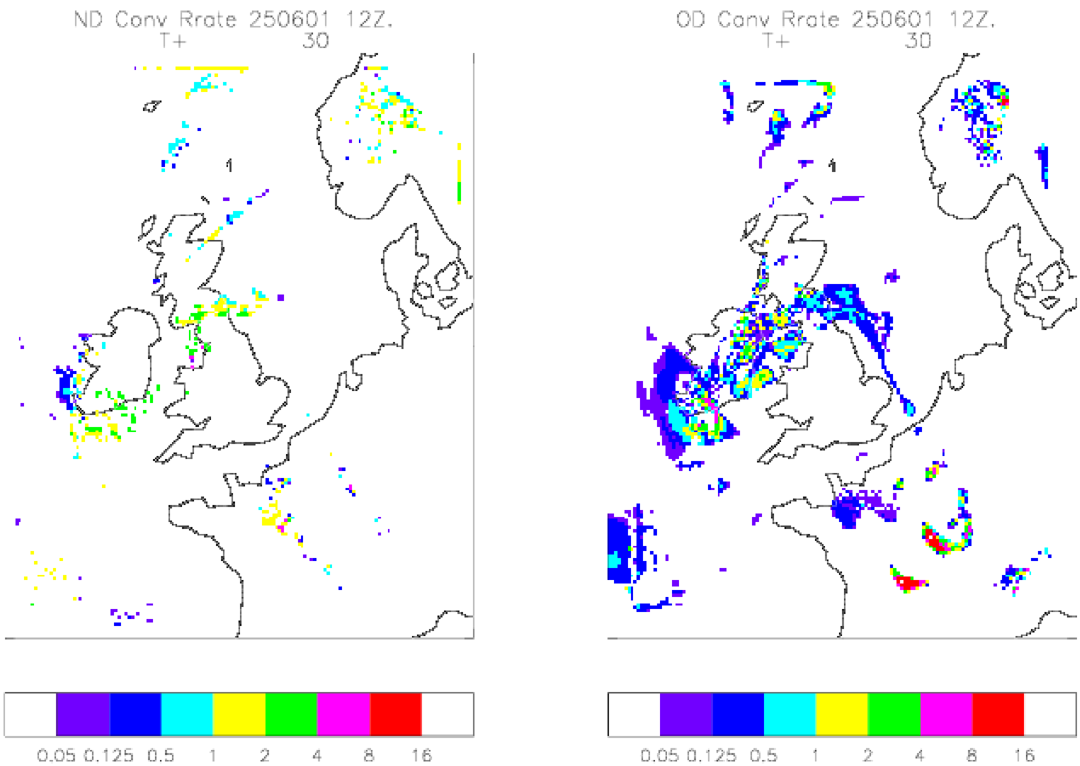


Figure 5.1 Very strong convection over France: t+30h forecasts of convective rain rate, New dynamics (left), Control (right)

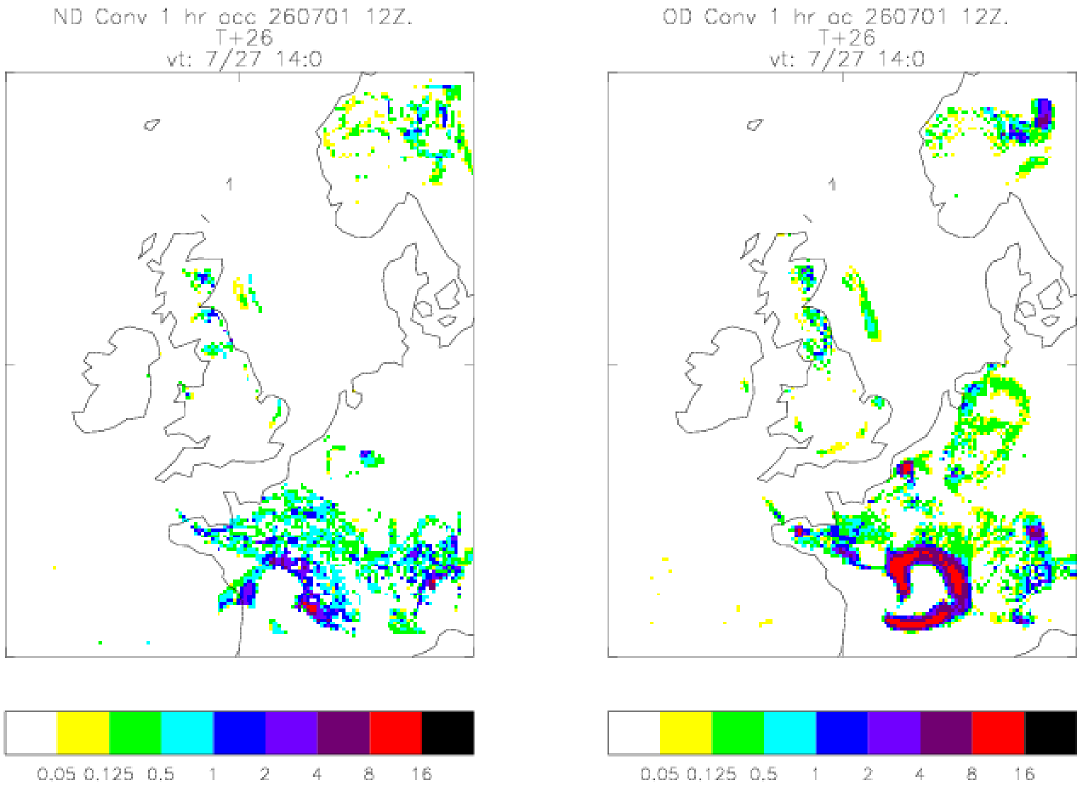


Figure 5.2 Very strong convection over France: t+26h forecasts of convective rain accumulations over previous hour, New dynamics (left), Control (right)

6. Summary of all verification

The signal from the first foggy period of the shadow suite implies an ND improvement in visibility, in agreement with the case studies. The whole shadow suite shows a slight detriment in precipitation skill, against both stations and Nimrod, again consistent with the cases. Screen temperature is improved slightly, while 10-metre wind and cloud cover give a mixed signal. The overall UK index for all forecasts is very slightly improved in the cases, but degraded in the extended sample of shadow suite results. Considering the subjective assessment of an overall neutral impact, the final judgment made on impact was 'not significantly different from neutral', allowing implementation to proceed.

References

Cullen, M.J.P., Davies, T., Mawson, M.H., James, J.A., Coulter, S.C. and A. Malcolm (1997). An overview of numerical methods for the next generation U.K. NWP and climate model. Numerical Methods in Atmospheric and Ocean Modelling. The Andre J. Robert Memorial Volume. ATMOSPHERE-OCEAN SPECIAL Vol. XXXV, No 1, Edited by Charles A. Lin, Rene Laprise and Harold Ritchie, pp 425-444.

Jones, C.D. and Macpherson, B. 1997: A Latent Heat Nudging scheme for the Assimilation of Precipitation Data into an operational Mesoscale Model. Met Apps, 4, 269-277

Macpherson, B., Andrews, P.L., Harcourt, S.A., Ingleby, N.B., Chalcraft, B.V., Maycock, A., Renshaw, R.J., Parrett, C.A., Anderson, S.R., Sharpe, M., Harrison, D.L., Gibson, M: 2002: The Operational Mesoscale Data Assimilation System 1999-2001: Implementation of 3DVar and Later Upgrades. Forecasting Research Technical Report No 374.

Appendix - New Dynamics Fact Sheet

A major upgrade to the Met Office Global Numerical Weather Prediction model took place in August 2002. The package of changes was under trial for almost a year and is collectively known as 'New Dynamics'. This appendix details some of the key changes, which are part of the New Dynamics package, along with the expected benefits.

- Non-hydrostatic model with height as the vertical co-ordinate.
  Full equations used with (virtually) no approximations. Suitable for running at very high resolution.

- Charney-Philips grid staggering in the vertical, i.e. potential temperature is on the same levels as the vertical velocity including top and bottom boundaries where vertical velocity is zero.
  Improved thermal wind balance, no computational mode, better coupling with physics and data assimilation, less noise and better stability.

- C grid staggering in the horizontal, i.e. u-component is east-west staggered from temperatures and v-component north-south staggered.
  Improved geostrophic adjustment, no grid-splitting, better coupling with physics and data assimilation, less noise and better stability.

- Two-time level, semi-Lagrangian advection and semi-implicit timestepping.
  Accuracy, efficiency (long timestep), shape preservation, conservation, reduced filtering, better coupling with physics and data assimilation, less noise and better stability.

- Edward-Slingo radiation scheme with non-spherical ice spectral files.
  Ice crystals are modelled as planar polycrystals with sizes related to the temperature (Kristjansson et al. (2000) .
  Gaseous transmission treated using correlated-k methods (Cusack et al.1999) with 6 bands in the SW, 9 in the LW (Cusack et al. has 8 in the LW, but we split one of these in HadAM4 and this configuration has gone into ND). The CKD continuum model is used (Clough 1989) .
  Fractional cloud treated as in Geleyn and Hollingsworth (1979) with convective and large-scale cloud distinguished.

- Large scale precipitation with prognostic ice microphysics.
  The new scheme employs a more detailed representation of the microphysics occurring within clouds. Water is contained in vapour, liquid, ice and rain categories, with physically based parametrization of transfers between the categories. The ice content becomes a prognostic variable within the model, rather than one diagnosed from a cloud scheme (Wilson and Ballard, 1999).

- Vertical gradient area large-scale cloud scheme.
  The standard Smith large-scale cloud scheme returns a cloud volume fraction which is assumed to take up the entire vertical depth of the gridbox and is therefore equal to the cloud area fraction. The vertical gradient method performs

the standard Smith cloud calculation at three heights per gridbox (on the grid level and equispaced above and below it), using interpolation of input data according to the estimated sub-grid vertical profiles. Weighted means are then used to calculate the volume data for the gridbox, while the area cloud fraction is taken to be the maximum sub-grid value. This modification allows the area cloud fraction to exceed the volume fraction and hence the radiation scheme, which uses area cloud, can respond to larger cloud area coverage and smaller in-cloud liquid water paths than the standard scheme would produce.

- Convection with CAPE closure, momentum transports and convective anvils.
  Diagnosis of deep and shallow convection; based on the boundary layer type diagnosis adopted in the Lock et al. (2000) boundary layer scheme. Convective cloud base defined at the LCL (and boundary layer scheme prevented from operating above this, so no longer overlaps with convection scheme).
  New parametrisation for convective momentum transports, based on a flux-gradient relationship. This is obtained from the stress budget by parametrising the terms (by analogy with scalar flux budgets) such that there is a gradient term associated with the mean wind shear (involving an eddy viscosity) and a non-gradient term associated with the transport (using a mass flux approximation).
  New cloud-base closures for thermodynamics and momentum transport. The thermodynamic closure for shallow convection follows Grant (2001) in relating the cloud-base mass flux to a convective velocity scale. For deep convection, the thermodynamic closure is based on the reduction to zero of CAPE over a given timescale (based on Fritsch and Chappell, 1980). These closures replace the standard buoyancy closure, which was found to be both noisy and unreliable. The momentum transport closure for deep and shallow convection is based on the assumption that large-scale horizontal pressure gradients should be continuous across cloud base.
  Parametrised entrainment and detrainment rates for shallow convection, obtained (Grant and Brown, 1999) using similarity theory by assuming that the entrainment rate is related to the rate of production of TKE.

- Boundary-layer scheme which is non-local in unstable regimes.
  Explanation: - the vertical diffusion coefficients are specified functions of height, over a diagnosed mixed-layer depth, that are scaled on both the surface and cloud-top turbulence forcing - also includes an explicit parametrization of entrainment at the boundary layer top
  Rationale: - more physical direct coupling between the turbulence forcing of unstable boundary layers and the transports generated within them (rather than the Ri-based scheme that relates fluxes to the local gradients within the layer) - numerically more robust

- Gravity-wave drag scheme which includes flow blocking.
  Strictly the new parametrization is best described as a sub-grid orography scheme - it consists of a GWD bit (due to flow over) and a non-GWD bit (the flow-blocking bit, which is due to flow around).
  The new sub-gridscale orography (SSO) scheme uses a simplified gravity wave drag scheme and includes a flow-blocking scheme. The new scheme is thus more robust and applies much more drag at low-levels.

- GLOBE orography dataset.

  Replace US Navy 10' orography data with 1' GLOBE orography data, averaged to 10'. The US Navy data has been used for over 30 years but is known to have many deficiencies. The GLOBE dataset is currently the best orography dataset that is freely available and is far, far superior to the Navy dataset. Before it is used in the model, the data is filtered using a sixth order low-pass implicit tangent filter, constrained so that the filtering is isotropic in real space.

- MOSES (Met Office Surface Exchange Scheme) surface hydrology and soil model scheme.

  This is already running in the operational model (Cox et. al., 1999).

References

Clough, S. A. and F. X. Kneizys and R. W. Davies, 1989, Line Shape and the Water Vapor Continuum, *Atmos. Res*., **23**, pp.229-241.

Cusack, S., and J. M. Edwards and J. M. Crowther, 1999, Investigating distribution Methods for Parameterizing gaseous absorption in the Hadley Centre Climate Model, *J. Geophys. Res*., **104**, pp.2051-2057.

Cox, P.M., Betts, R.A., Bunton, C.B., Essery, R.L.H., Rowntree, P.R. & Smith, J., 1999: The impact of new land surface physics on the GCM simulation of climate and climate sensitivity. *Climate Dynamics,* **15**, 183-203.

Fritsch, J.M. and Chappell, C.F. 1980. Numerical prediction of convectively driven mesoscale pressure systems. Part I: Convective parameterization. *J. Atmos. Sci.* **37**, 1722-1733

Geleyn, J.F., and A. Hollingsworth, 1979, An Economical Analytical Method for the Computation of the Interaction Between Scattering and Line Absorption of Radiation, *Beitrage Phys. Atmosph*., **52**, pp.1-16.

Grant, A. L. M., 2001: Cloud-Base Fluxes in the Cumulus-Capped Boundary Layer. *Quart. J. Roy. Met. Soc*., **127**, 407-422

Grant, A.L.M. and Brown, A.R., 1999: A similarity hypothesis for shallow cumulus transports. *Quart J. Roy. Met. Soc.,* 1913-1935

Kristjansson, J.E., and J. M. Edwards and D. L. Mitchell, 2000. The impact of a new scheme for the optical properties of ice crystals on the climates of two GCMs, *J. Geophys. Res*., **105**, pp.10,063-10,079.

Lock, A.P., Brown, A.R., Bush, M.R., Martin, G.M. & Smith, R.N.B., 2000. A new boundary layer mixing scheme. Part I: Scheme description and single column tests. *Mon.Wea. Rev.,* **128**, 3187-3199.

Wilson, D.R., and S.P. Ballard, 1999. A microphysically based precipitation scheme for the UK Meteorological Office Unified Model, *Quart. J. Royal Meterol. Soc*., **125**, 1607-1636.