1 SUMMARY

A 4 km gridlength configuration of the Met Office Unified Model has been developed and extensively tested over the last two years. It shows improvements over the current 12 km operational configuration in forecasting near surface parameters and precipitation patterns, particularly orographic enhancement of precipitation and organised convection events. It is expected that an operational 4 km model will bring benefit to the Severe Weather Warning Systems in place at the Met Office and to users of near surface variables, including aviation and highways operations; the data from the new model will also be used by the Met Office’s nowcasting systems. A basic configuration using initial conditions interpolated from the operational North Atlantic European model (12 km horizontal gridlength) has been operational from April 2005, with the introduction of data assimilation expected in December 2005.

2 INTRODUCTION

The development of the non-hydrostatic, semi lagrangian-semi implicit version of the Met Office’s Unified Model (UM) has provided the capability of developing configurations of the UM at convective scale resolutions; these configurations are needed to provide valuable NWP guidance for hazardous weather, particularly flash floods, hail storms and strong winds, often linked with meteorological phenomena at this scale and not captured by the current operational models at the Met Office. Other benefits arise from the use of a finer grid model, such as more accurate representation of the surface parameters, leading to improved forecasts of processes dependent on them, such as fog formation and dissipation, and orographic enhancement of precipitation.

The summer 2004 witnessed various severe convective episodes, the most noticeable being the flash flood that devastated the village of Boscastle (Cornwall, South West England) on the 26th of August and was missed by the operational models, with the highest resolution being around 12 km gridlength. At the time, the experimental 4 km and 1 km gridlength models (High Resolution Trial Models, referred as HRTM) were in an advanced state of development, and their capability in forecasting such events was demonstrated. May et al. (2004) show that low level convergence modulated by local topography and land sea contrast was a key factor in the localisation and persistence of the precipitation; the report (May et al 2004) recommended implementing a high resolution operational model as soon as feasible, quoting 4 km gridlength as the most cost effective option; it was emphasised, however, that small scale uncertainty can lead to positional errors in the precipitation forecast and hence raw model data was not suitable for direct output to the public.

Recent upgrades in the computing infrastructure at the Met Office, with the replacement of the supercomputer by a NEC with 30 SX-6 nodes (8 Gflops theoretical computational rate per processor) in September 2003 and the addition of 15 SX-8 nodes (16 Gflops theoretical computational rate per processor) in February 2005, giving an overall nominal peak performance of 3.8 Tflops, have provided the means to produce operational NWP guidance at high resolution with a 4 km gridlength model. The description of the model, results of pre-operational tests and evaluation of the first operational months are the subject of this poster.

3 DESCRIPTION OF THE MODEL

The bulk of the development work has been done with the HRTM models; these are centred on the Chilbolton Radar, which provides observational data for evaluation and validation. The 4 km HRTM is used for research and also to provide lateral boundary conditions to the 1 km HRTM, and covers South England, the Midlands and Wales (fig. 1). The operational model (UK4) domain covers Great Britain, Ireland, Hebrides, Orkneys, the English Channel and the western part the North Sea, the gridlength is 0.036 degrees (approximately 4 km), with 320 rows and 288 columns (fig. 2). The vertical resolution was chosen to be 38 levels for consistency with the driving models and hence avoid vertical interpolation in the lateral boundaries; boundary layer computations take place in the lowest 13 levels. It is planned to improve the vertical resolution of all operational configurations of the UM (Global, Regional and UK) to around 70 levels by summer 2006.

Both the baseline of the experimental 4 km model and the operational model share the same scientific options; a brief description of the dynamic core and physical parametrization schemes follows.

The dynamical core is common for all UM configurations and consists in a non hydrostatic semi-lagrangian advection scheme and semi-implicit time integration,
Cullen et al. (1997); horizontal discretization is done in a staggered C grid, and vertical discretization in a staggered Charney-Philips grid; vertical levels are specified by a normalised height coordinate that follows terrain in the bottom model level and defines a constant radius surface above a prescribed level (30 in the current configuration, equivalent to 17500 m above zero orography). The time step is 100 seconds.

The boundary layer turbulent mixing is represented by a first order non-local K scheme with explicit entrainment parametrization, Lock et al. (2000). Horizontal diffusion is performed over U, V, Q and Theta using a Del-4 operator to prevent excessive development of grid scale structures. The parametrization of cloud and precipitation microphysics is performed by a mixed-phase scheme, Wilson and Ballard (1999) with advection by 3D winds of precipitation products. The radiation is parametrised by a two stream scheme, Edwards and Slingo (1996), using 5 spectral bands for long wave and 5 for short wave.

Regarding convection, the common assumption in the current schemes, i.e. a grid box is much larger than the area of the updraughts, no longer holds for models with this resolution; ideally the convection should be resolved explicitly by the dynamics and microphysics, but in a 4 km gridlength model there are still some situations, particularly shallow convection, that need to be parametrised. The convection scheme used in this configuration is a modification to the usual penetrative mass flux scheme with CAPE closure, described in Gregory et al. (1997); Instead of using a constant CAPE closure timescale, this is made linearly dependant on CAPE for large CAPE values, reducing the mass flux and hence curtailing the activity of the convection scheme for deep convection, but leaving the scheme to operate for shallow convection. The shape of the function describing the CAPE closure timescale has to tend asymptotically to a constant when CAPE tends to zero, to obtain the parametrised behaviour of shallow convection, and grows with CAPE for large values of CAPE (CAPE much larger than a prescribed constant C), so inhibiting the parametrization of deep convection; the chosen formulation has been

\[
\tau(CAPE) = \left(\frac{t}{C}\right) \cdot CAPE + \exp(-\frac{CAPE}{C})
\]

where \(t\) is the minimum CAPE closure timescale in seconds for very small CAPE and \(t/C\) is related to the limit to the cloud-base mass flux (Roberts (2003a)).

Fields of surface parameters have been extracted and processed from the IGBP dataset (Loveland et al. (2000)) for land-sea mask, a high resolution dataset for orography, and for land use ITE dataset over Great Britain and IGBP elsewhere.

4 PRE-OPERATIONAL TESTS

Several combinations of the two tunable parameters for the modified convection scheme were tested with the HRTM 4 km model, as well as the no modified convection scheme (fixed CAPE timescale) and the convection scheme switched off and are described by Lean et al. (2005) in the context of the HRTM 1km development. The results are not conclusive in terms of the selection of a best option for the convection scheme, as different situations are better handled by different options (i.e. scattered convection is better captured with the operational convection scheme with a fixed CAPE timescale whilst
explicit microphysics performed better in case of organised convection); it was found also that having no convection scheme led to the generation of too few structures, too large and too intense, overestimating the total rainfall over the domain. Tests with the CAPE dependent CAPE timescale for different parameters revealed that the total precipitation was reduced when the convection scheme was made less active, leading to underestimations in the scattered convection situations, and that reduction in the activity of the convection scheme produced a delay in the onset of the convection of up to two hours. The reason for this delay in the initiation of convection is that the process is triggered by sub-grid scale disturbances not captured by the model but considered in the design of the convection scheme; when examining the precipitation partitioned between dynamic and convective, the effect of the convection scheme in the initiation of convection was seen to delay more the onset of the explicitly resolved convection.

Figure 3: comparison of accumulated precipitation between model and radar for different periods. Top row shows 6hr accumulation for the model from T+18 to T+24 (a) and radar validation (b). Bottom row shows 24hr accumulation from T+0 to T+24 (c) and radar validation (d). Model data time is 18:00 UTC on 11/06/2004.
Sensitivity tests of the diffusion scheme with the HRTM models revealed that the effect of increasing the horizontal diffusion of moisture was a general reduction in the grid scale structure of the precipitation, but also a decrease in the total rain over the domain and a further delay in the onset of convection. Testing the frequency of update of lateral boundary conditions showed that above 30 minutes the 4km HRTM sometimes developed numerical noise propagating from the boundaries, this effect was most noticeable in an unrealistic break up of fronts.

Tests using the operational domain included a set of 21 case studies representative of a wide range of synoptic situations (Annex 1). These tests were driven by re-runs of the operational UK-MES model (12 km gridlength, see Fig. 1 for domain), which also provided the initial conditions and was used as control run in the validation; only the recommended settings arising from testing in the 4 km HRTM model were tested to assess suitability for operational implementation.

Even though some of the cases were selected to test the model in extremely unstable situations (i.e. 03/08/2005), the model proved to be very robust, without major numerical problems. When numerical features were present it was in the form of lines of moderate or heavy precipitation 1 grid box wide by several grid boxes (up to 15) long; such structures eventually fade naturally without affecting the forecast more than leaving sometimes a straight line in the accumulated precipitation.

Small scale structure is present in most of the accumulated precipitation fields. Comparison with NIMROD accumulations (produced from the quality controlled UK radar composite) shows reasonable qualitative agreement when the accumulation period is 6 hours, as part of the detail is retained in the radar data; however the 24hr accumulation comparison still shows small scale structure in the model whilst it is smoothed out in the NIMROD data. (Fig. 3, previous page), reiterating the necessity to post process the precipitation fields. Averaging the fields to a 12 km grid for a fair comparison with the driving model showed much better agreement (fig. 4).

Verification of the averaged accumulation precipitation field using the intensity scale technique, Mittermaier and Wilson (2005), reveals a marginal improvement against the UK-MES model. Objective verification results show a reduction of negative bias in pressure at
mean sea level against the control (fig. 5) and a consistent negative bias in the fractional cloud cover (fig. 6). However, there is an enhancement applied to the generation of cloud amount in the UK 12 km mesoscale model, which may be partially responsible for this difference.

A continuous trial was run from the 1st of March until the 1st of April, driven by the operational North Atlantic and European (NAE) configuration of the UM (12 km gridlength) twice a day with data times 00 and 12 UTC; the initial conditions were obtained interpolating from the driving model. This trial confirmed the existence of a negative cloud bias that produced a diurnal cycle in the screen temperature mean error (fig. 7). It also showed that pressure at mean sea level is strongly conditioned by the driving model, closely following the NAE error signature (Fig. 8); this is not surprising, since the absence of assimilation cycle and the small dimensions of the domain prevent the model to develop its own solution.

Although the forecasts of low and medium cloud are worse compared with the other operational models, the benefit of high resolution and better definition of the surface variables is noticeable in the better forecast of fog (fig. 9).

### 5 OPERATIONAL PERFORMANCE

The UK4 model has been operational since the 13th of April, running once a day at 00:00 UTC, driven by the NAE operational model that also provided the initial conditions. The weather affecting the U.K. from April to June has been varied, capturing most of the spring situations. Both the objective and the subjective verification results confirm those found in the pre-operational tests, although the absence of a 12:00 UTC run does not permit a full evaluation of the screen temperature forecast bias. Verification of accumulated precipitation using the intensity scale technique for May show overall improvement over the UK-MES model for large thresholds over 2 mm/day and scales larger than 24 km (Mittermaier and Wilson (2005)). On the 14th of June, a new run at 12:00 UTC was introduced.

Feedback from forecasters was sought since the operational implementation, providing very valuable information about the model performance from the user perspective. The model was accepted as a useful tool for forecasting, and its ability to capture the orographic enhancement of rain over the Pennines on the 1st of June (fig. 10) was noticed; it was confirmed, however, a tendency to overforecast precipitation in unstable situations, sometimes producing spurious rain, as in the 31st of May (fig. 11).

### 6 CONCLUSIONS

A 4km gridlength model has been introduced operationally at the Met Office, with several upgrades scheduled for the coming months. Results of pre-operational tests and evaluation of the first operational month show potential to improve the NWP guidance of severe weather events and near surface variables. It has been shown that the UK4 model has not yet reached the level of performance of the more mature operational models; this
Figure 9: Forecast of fog fraction at 00Z on 01/04/2004 by the UK4 model (left) and operational UK-MES model (right) at 24 hr lead time. Synop observations are superimposed.

Figure 10: Model total precipitation rate at T+21 from the 01/06/2005 00:00 UTC forecast (left) and validating radar image (right), the precipitation structure is located in the middle of the images.

wasn’t unexpected, as the current configuration lacks a data assimilation procedure and is in early stages of its life cycle, with plenty of scope for improvement. Even in these circumstances, the forecast of fog is generally better than the coarser resolution operational models, and the total precipitation in convective events is also improved; it was not expected to capture the detail in the very fine scale location of the precipitation, and this has been confirmed, highlighting the need of a probabilistic approach in the distribution of products, Roberts (2003b).

Some areas that will benefit from further development, such as negative bias in cloud fraction and numerical structures in the precipitation fields, have been identified and are actively being worked on, with an expected upgrade package to be introduced in August 2005.

The introduction of a data assimilation system in December 2005 will bring further improvements, mainly to the forecast of precipitation at very short range, so increasing the nowcasting capability of the Met Office.

REFERENCES
Figure 11: Model total precipitation rate at T+14 from the 31/05/2005 00:00 UTC forecast (left) and validating radar image (right), the scattered convection forecasted over East Anglia and the Midlands is not visible in the radar image.


Met Office Technical reports are available online at http://www.metoffice.com/research/nwp/publications/papers/technicalreports/index.html
7 ANNEX 1, CASE STUDIES
04/03/2004 00:00 UTC: Stratus and Fog
07/03/2004 12:00 UTC: Stratocumulus
11/03/2004 00:00 UTC: Snow
06/04/2004 00:00 UTC: Diurnal convection and Gales
19/04/2004 00:00 UTC: Diurnal convection
27/04/2004 00:00 UTC: Thunderstorms
03/05/2004 12:00 UTC: Active fronts and Gales
01/06/2004 00:00 UTC: Active fronts (summer)
21/06/2004 12:00 UTC: Stratocumulus
03/08/2004 00:00 UTC: Organised convection (summer)
11/08/2004 18:00 UTC: Organised convection (summer)
15/08/2004 12:00 UTC: Organised convection (summer. Boscastle event)
16/08/2004 00:00 UTC: Organised convection (summer. Boscastle event)
13/10/2004 12:00 UTC: Fog in central England and unstable elsewhere
12/11/2004 00:00 UTC: Active front
06/12/2004 12:00 UTC: Stratocumulus
12/12/2004 12:00 UTC: Stratus and Stratocumulus
07/01/2005 06:00 UTC: Organised convetion (winter)
12/01/2005 12:00 UTC: Clear winter night
17/01/2005 00:00 UTC: Snow
19/01/2005 18:00 UTC: Gales