4B.3 EXPERIENCES WITH A 1.5KM VERSION OF THE MET OFFICE UNIFIED MODEL FOR SHORT RANGE FORECASTING

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1. INTRODUCTION

The Met Office has introduced a variable resolution 1.5km UK version of the MetUM (UKV) as part of the routinely running operational system. This model follows on from the successful introduction of a 4km UK model (UK4) about 5 years earlier. A major aim of introducing this model was to improve the model representation of convection although it was hoped that forecasts of other parameters would also improve. The model has been running for around a year now. The purpose of this paper is to describe the rationale behind this model and report initial conclusions about its performance. We also make reference to earlier research work which was carried out with a 1-km gridlength model.

2. DESCRIPTION OF MODEL

The UKV is a variable resolution configuration of the MetUM whose domain is shown in figure 1. The inner domain with a gridlength of 1.5km covers almost all of the United Kingdom. Outside that is a transition region where the gridlength smoothly increases to 4km and beyond there is a region where the gridlength is 4km. This is true independently in the x and y directions so the result is cells around the edge with size 1.5x4km with 4x4km cells only in the corners.

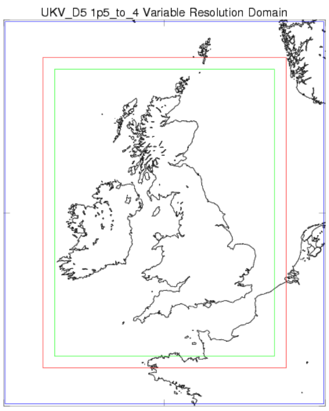

Figure 1. UKV domain. Green line is 1.5-km inner area, red is outside of the transition region.

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This model is one way nested inside the North Atlantic European (NAE) model which has a 12-km gridlength with the boundary updated every 30 mins. The model uses a 3 hourly 3d-var assimilation cycle with nudging for radar reflectivity data and runs out a forecast to T+36 on every other cycle (i.e. every 6 hours).

Most of the physics in the model is unchanged between the 1.5-km UKV, the 4-km UK4 model and the 12-km NAE. A major difference is in the treatment of convection. The 1.5-km model runs with no convection parametrization whereas the 12-km model uses the Gregory Rowntree mass flux convection scheme (Gregory and Rowntree 1990). As described in Lean et al (2008) the 4-km model runs with the convection scheme modified so that the mass flux is restricted depending on the CAPE. In addition there are differences in the microphysics with the 4-km and 1.5-km models using prognostic rain whereas the 12-km model diagnoses rain which effectively falls out instantaneously in the same gridbox. Taking advantage of the semi-lagrangian dynamical core the UKV model runs with a 50s timestep.

3. BENEFITS OF HIGH RESOLUTION

As discussed previously (e.g. Lean et al 2008) there is a good deal of evidence that the 4-km and 1.5-km models often do better than a 12-km model for convection. In many cases the benefits are a result of having convection represented explicitly rather than by a convection scheme. In principle explicit deep convection is very under-resolved even at 1.5-km but, in practice, it often represents it well. The convection scheme responds to the model fields on each timestep and hence has no memory. So rather than convective cells advecting the convection tends to switch on and off on each timestep on a gridpoint by gridpoint basis. The convection scheme will tend to miss any organisation of convection that occurs. Lean et al (2008) also show that a 1-km model gives better results than a 4-km model. The explicit convection is severely under-resolved in many situations in the 4-km model. This leads to there often being too few cells which are too large and too intense. In many cases lines of convection are broken up into cells. Many of these effects can be

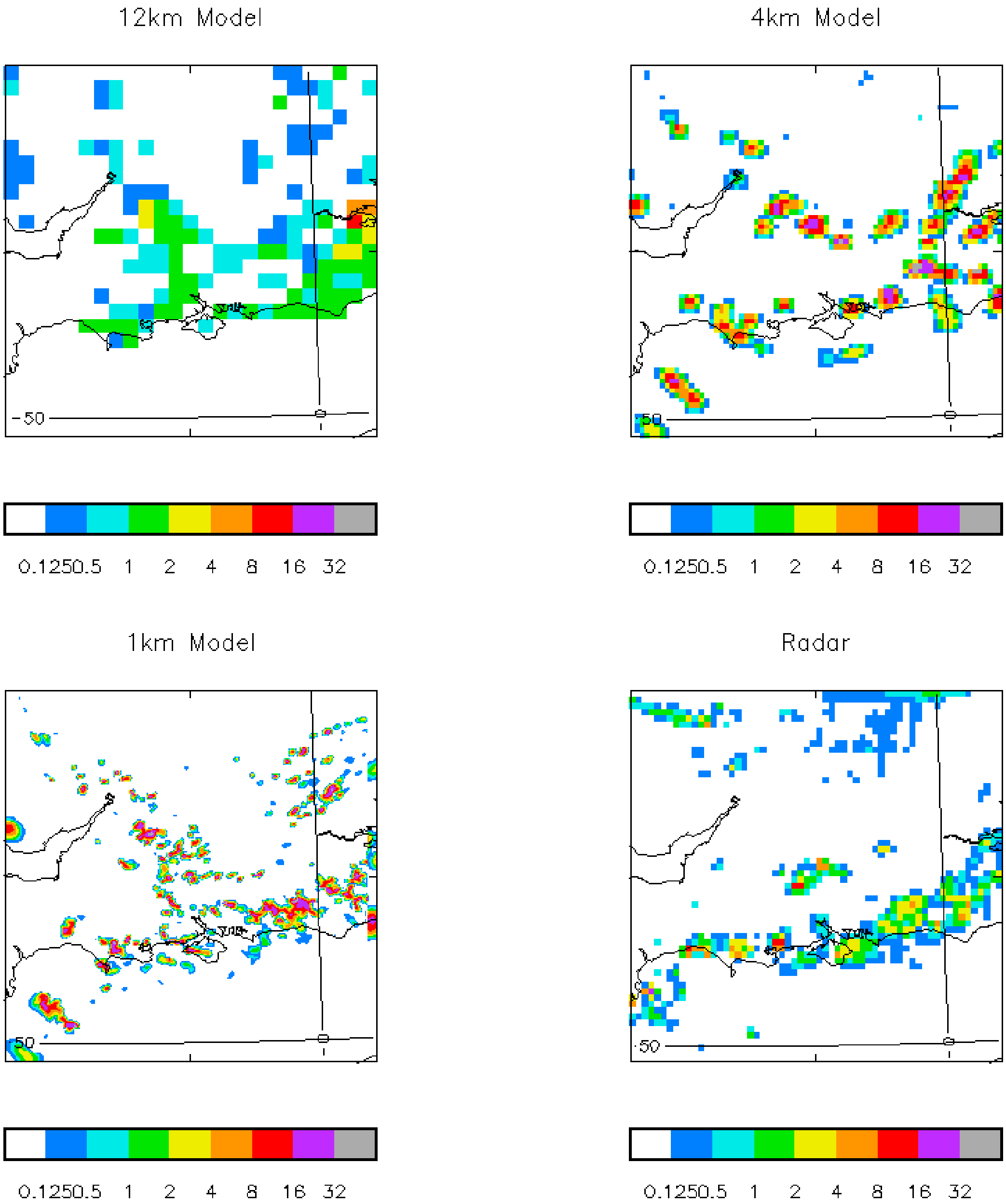

Figure 2. Comparison of case of line of convection between 12-km, 4-km and 1-km models with radar.

seen in figure 2 which compares the representation of a case in 12-km, 4-km and 1-km research models with a radar image. The 12-km with a convection scheme shows no real indication of the line of convection. The 4-km model tries to produce it but breaks it up into large cells because the resolution is not sufficient. The 1.5-km model represents the scales of the line much better.

Also discussed in Lean et al (2008) was the fact that explicit convection in a 4-km model introduces a delay in initiation. This is due to the fact that the initial stages of the convection cannot be represented on these scales and so it starts later after more CAPE has built up. In contrast a 1-km model is found to have a much smaller delay in initiation. This manifests itself in a number of ways and example is shown in Figure 3 which shows a case of lines of showers along convergence lines in the SW of the UK. Due to the delay of initiation the convection only appears on the convergence lines in the 4-km model much further downstream. In the UKV model the showers start further upstream in agreement with the radar.

In addition to the benefits for convection it is expected that higher resolution will give other benefits. Features such as convergence lines and sea-breezes etc

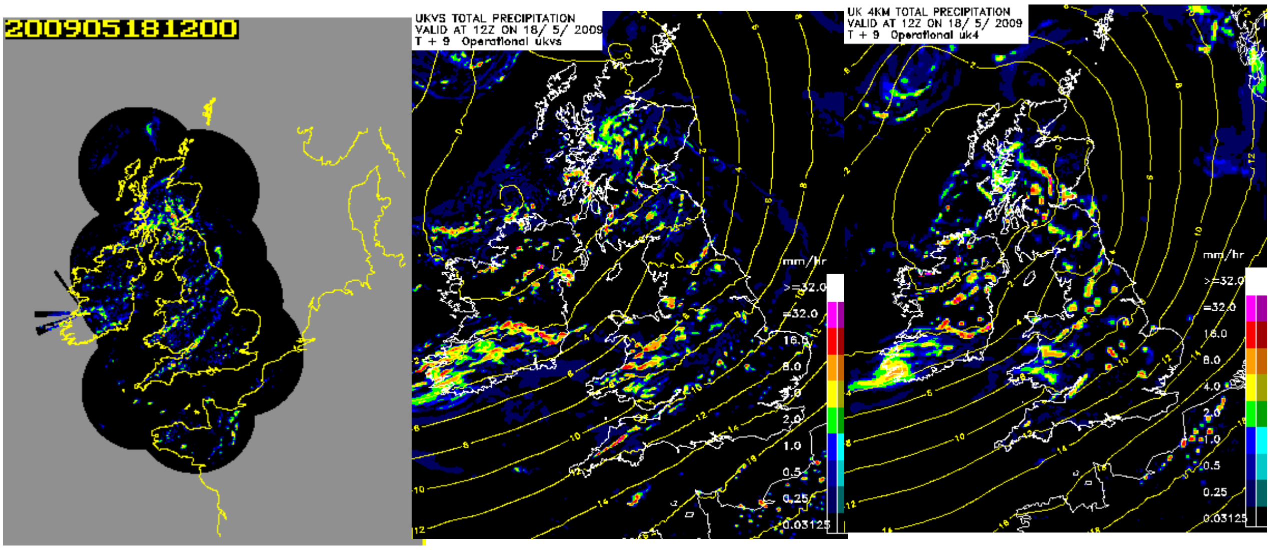

Figure 3. Radar image (left), UKV model (centre) and UK4 model precipitation fields. N.B. in the centre pane only the inner, 1.5-km part of the UKV domain is shown.

are expected to be better represented which can often have a beneficial effect. The case shown in figure 3 is better also because the convergence lines are better represented at higher resolution.

Higher resolution also gives better representation of orography which is expected to improve forecasts of area coverage of fog and also of other parameters such as screen temperature. It is found that orographic rain is better represented when a more detailed orography dataset can be used. Roberts et al (2009) show big improvements in the rain amount and distribution of orographic rain over Cumbria, UK, when going from a 12-km to a 4-km to a 1-km model. Finally running at high resolution opens the door to the possibility of assimilation of high spatial resolution data such as radar reflectivity data.

4. VARIABLE RESOLUTION AND ITS BENEFITS

The variable resolution version of the MetUM is described by Tang et al (2011), It has been optimised such that the cost per gridpoint per timestep is the same as for the fixed resolution model. Comparisons of the variable resolution model with an approximately equivalent nested system give confidence that the presence of variable resolution does not, in itself, change the character of the model solutions (despite there being gridboxes with a non-unity aspect ratio). In principle there is an issue with physics settings in the model that need to change with gridlength but, in practice, with a 1.5-4km model we have been able to keep the same physics over the whole domain (of particular interest is the fact that we run the whole domain with no convection paramaterisation). This is expected to be a subject of future work in case we want to move to models with a larger range of gridlengths.

The particular reasons for running the UKV model with variable resolution are listed below:

1 .An alternative is to nest a 1.5-km model directly inside the driving 12-km model. This represents a 1:8 nesting ratio. Although this was shown to run in a number of cases during testing it is likely to introduce artifacts, particularly when features such as sharp fronts enter the domain.

2. A second alternative would be to run a 12-km, 4-km and 1.5km system of three nested models. This is complicated and might be viewed as unnecessarily expensive if, in the future, there is no business need for a 4-km model. Also it is possible that the problems with convection in the 4-km model would adversely affect the 1.5-km model. Finally the nest from 4-km to 1.5-km implies storing a large amount of data which would, in practice, limit the boundary updating to every 30mins which might introduce artifacts as shown in figure 4.

3. An issue with these models is the spin up of convection as air enters the model through the boundaries from the driving model which has parameterized convection. Having the low resolution part of the domain around the edge effectively moves the boundary further away from the area of interest at lower cost than simply

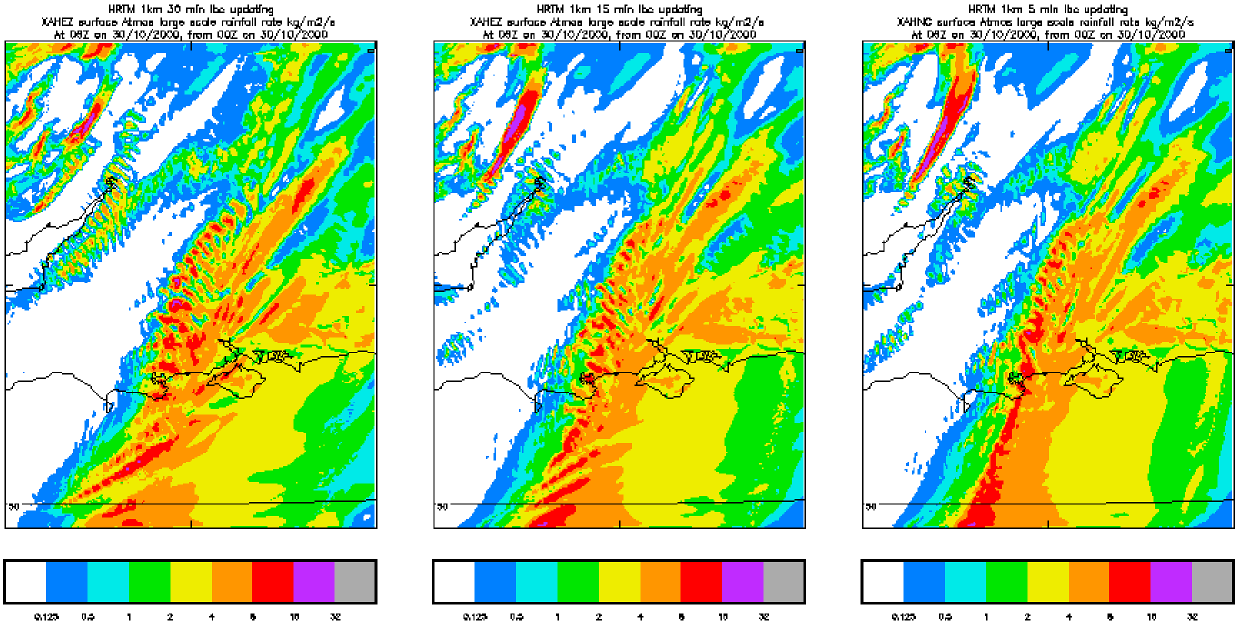

Figure 4. Precipitation rates for a case of a front crossing S England for a 1-km model driven by a 4-km model with boundary updating frequency of 30min (LHS), 15min (centre) and 5min. Note how a 5 minute updating frequency is required to avoid breaking up the front.

extending the high resolution domain. Figure 5 shows an example of this of showers in a westerly flow. In the radar there are showers to the west of Scotland and over the whole of Ireland. In the UK4 representation there are few showers over the western third of Ireland and none to the west of Scotland. This is due to the spin up issue as the unstable air enters the domain on the western boundary. In the UKV the shower distribution is much closer to that in the radar. This is partly because the initiation is quicker with the 1.5-km gridlength but also because of the presence of the lower resolution part of the domain which allows the showers to start spinning up. The variable resolution allows the boundary with the model with parametrized convection to be moved further from the region of interest at lower cost.

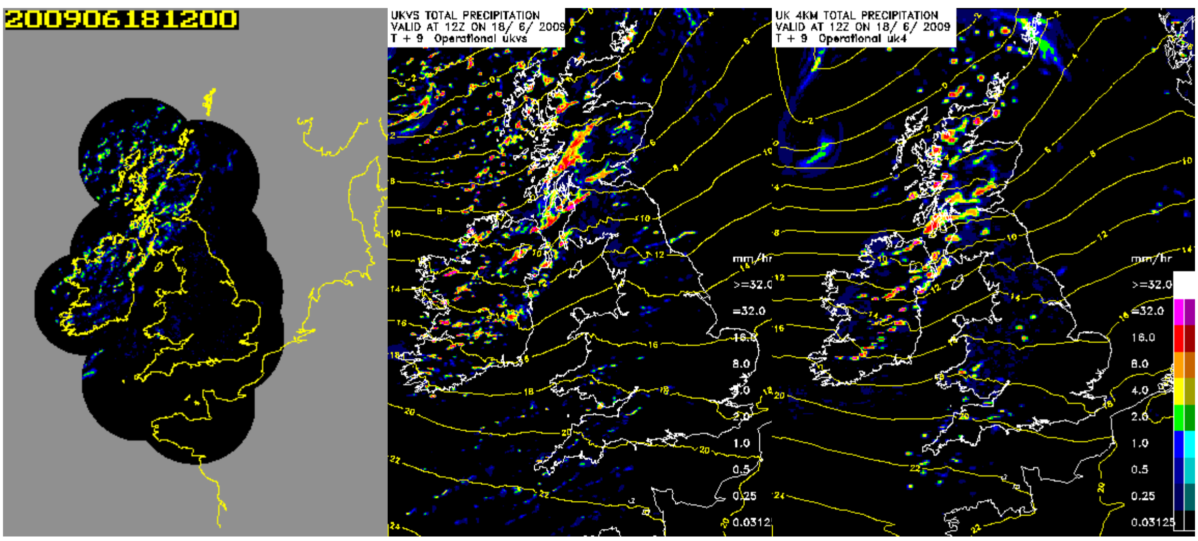

Figure 5. Precipitation fields from radar (LHS), UKV model (centre) and UK4 for 12 UTC on 18th June 2009. N.B. the centre pane shows only the inner, 1.5-km part of the UKV domain.

5. VERIFICATION

In this section we present some preliminary results for verification of this model. Verification has been running on this model for much of 2010. Most of the verification metrics which have been used are of the traditional gridscale RMSE and bias type. By these metrics most variables (10m wind, screen temperature etc) show a broadly neutral or beneficial effect of going from the 12-km model to 1.5-km. There, is however, an impact on the scores for most fields in upscaling the 1.5-km fields before performing the verification which shows the trade off between removing the "double penalty" verification artifacts and losing genuine small scale information.

For precipitation the traditional gridscale Equitable Threat Score (ETS) score against rain guage point observations shows that the 4-km and 1.5-km models are worse than the 12-km. However this is misleading because the high resolution models get penalised in this score for having the correct details in the wrong place. In contrast the 12-km model which has much blander fields and no chance of predicting high rainfall totals which cause local flooding events does better in the score.

A more appropriate verification technique which takes into account the likely location errors on small scales has been developed by Roberts and Lean (2008). This approach uses a Fraction Skill Score (FSS) on probabilities generated by a neighbourhood method. The probabilities are calculated using a neighbourhood around each gridpoint whose size determines the minimum scale taken account of in the verification. Figure 6 shows an example of these scores as a function of time over a 6 month period for the three models. Because the scores may vary greatly from forecast to forecast (and will be absent altogether if there is no rain) the curves shown are a 10 day running mean.

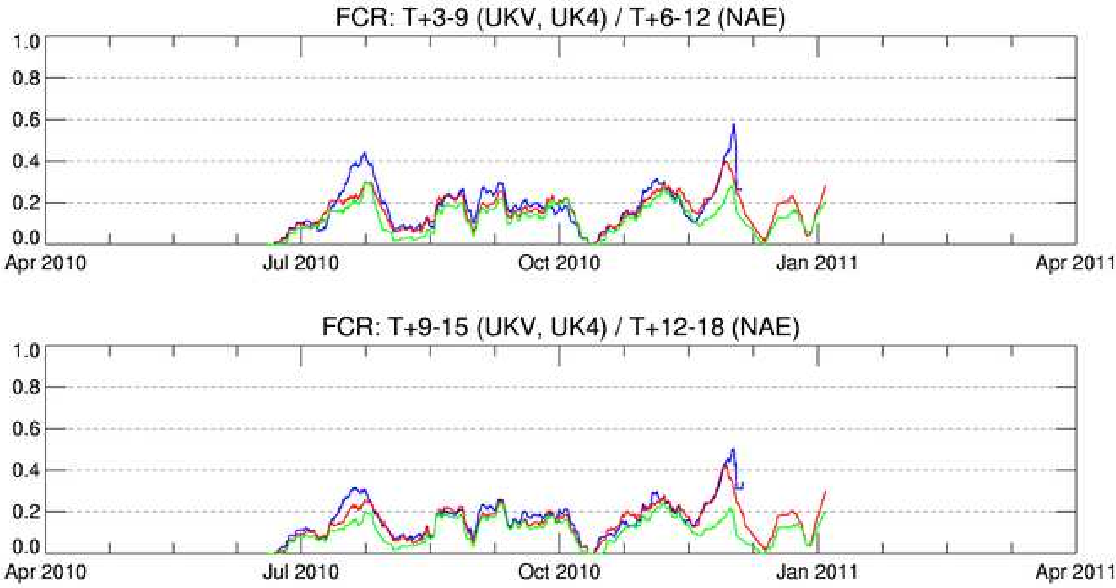

Figure 6. 10 day running mean of FSS scores for a threshold of 8mm in 6 hours for a 25km scale length. Green is NAE, red is UK4 and blue is UKV.

In this example the UKV is generally better than the UK4 which is generally better than the NAE although this is not true at all times.

Table 1 shows the comparison of scores for a number of thresholds (given as accumulated rain in 6 hours). The rows represent different forecast ranges of the six hour periods (1 is T+3 to T+9 for the UKV, 2 is T+9 to T+15 etc). The percentages represent the percentage of verification times that the higher resolution model scored better minus the percentage that it scored worse. The overall positive percentages in the table bear out that, overall, the UKV model does better than the NAE by this score. The green shaded cells indicate statistically significant differences (stronger shading implies more significance). Table 2 shows the same scores comparing the UK4 with the UKV. Although the percentages are lower in this case showing that the models are much closer in performance, they are still all positive, showing that the UKV is still doing better than the UK4. As was mentioned at the start of this section all these scores should be regarded as preliminary since the UKV has not been running for very long. More robust statistics will be obtained over a longer time period.

	0.5mm	1mm	4mm	8mm	16mm
1	35%	31%	40%	41%	30%
2	34%	27%	35%	41%	25%
3	25%	28%	33%	36%	26%
4	30%	27%	37%	39%	24%
5	31%	28%	42%	39%	25%

Table 1. Comparision of FSS scores comparing UKV with NAE. For details see text.

	0.5mm	1mm	4mm	8mm	16mm
1	14%	22%	18%	18%	14%
2	17%	18%	10%	11%	5%
3	13%	8%	3%	7%	3%
4	12%	13%	5%	6%	2%
5	15%	15%	15%	1%	3%

Table 2. Comparision of FSS scores comparing UKV with UK4. For details see text.

6. PREDICATBILITY/INTERPRETATION ISSUES

Models of this gridlength raise major issues of interpretation due to the low predictability of features on small scales. These are the same issues that make verification difficult as discussed the last section.

Because the model has a gridlength of 1.5-km does not mean that forecasts can be issued with that amount of detail. In many cases small scale details will not be predictable and will be wrongly positioned. A good example would be an area of showers such as the one to the west of Scotland in figure 5. Although the general area of shower activity is likely to be correctly predicted by a good model, the locations of the individual showers will not be. It is important to avoid presenting forecast information to customers in such a way that they might take such information literally. A complicating factor is that there will be situations where individual showers *are* predictable when they are driven by large scale features. For example Lean et al (2009) described a case of a single storm initiating over orography as a result of a convergence line interacting with a front.

The problems that can arise are well illustrated by the case which caused floods over Bodmin Moor, an area of high ground in SW England, in November 2010. It was noticed that the accumulated rainfall in the area was much higher in the UK4 model than the UKV resulting in the UK4 agreeing much better with observations. Precipitation fields from this case are shown in figure 6.

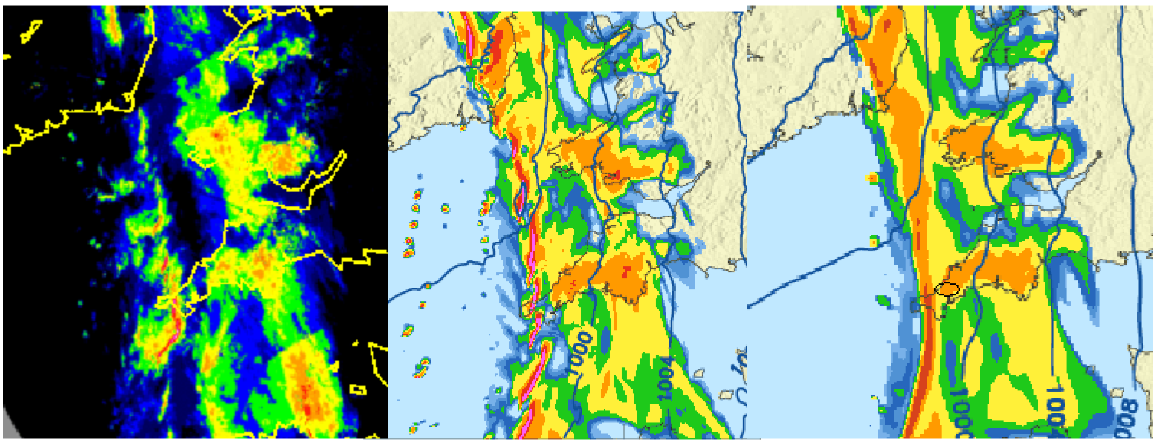

Figure 6. Precipitation fields from Radar (left) UKV model (centre) and UK4 for 3UTC 17th Nov 2010. The approximate location of Bodmin Moor in SW England is shown by the elipse in the right hand image.

The frontal structure in the UK4 was very uniform whereas in the UKV it was broken up into line segments which agrees well with the radar image. The heavy rain in the radar image was a result of one of those line segments crossing the higher ground of Bodmin Moor and being orographically enhanced. Although the UKV represented the general frontal structure better than the UK4 the small scale line segments were not correctly positioned and so the heavy rain did not appear. In contrast in the UK4 the rain on the very uniform front was enhanced leading to high totals.

The solution to these problems is to ensure that any small scale information is presented probabilistically. The best approach would be to run an ensemble of convection permitting models and this is the subject of current work. Alternative approaches which are not so computationally expensive are to separate the unpredictable scales or the use of lagged ensembles. The method for separating the unpredictable scales is to take a neighbourhood around each grid point and calculate a probabilitiy over this area. Research is ongoing into these approaches.

7. CONCLUSIONS

The Met Office is routinely running a variable resolution 1.5km version of the Met UM over the UK. We have shown that the representation of convective rainfall in this model benefits both from the 1.5-km gridlength over most of the domain and also from having a variable resolution zone around the edge. This model produces significantly better forecasts of convection than the more traditional regional models with order 10-km gridlength. A major issue with these models is the lack of predictability on small scales and both verification methods and the presentation of results need to take this into account. In future we plan to address the predictability problem by running ensembles of convection permitting models.

References

Gregory, D., and P. R. Rowntree, 1990: A mass flux convection scheme with representation of cloud ensemble characteristics and stability-dependent closure. *Mon. Wea. Rev.*, 118, 1483-2013 1506.

Lean H W et al. 2008: Characterstics of High Resolution Versions of the Met Office Unified Model for Forecasting Convection over the UK". *Mon. Wea. Rev.* 136 3408-3424

Lean H W et. al. 2009: The Surprising role of Orography in the Initiation of an Isolated Thunderstorm in Southern England. *Mon. Wea. Rev.* 137 3026-3046

Roberts N.M et. al. 2009. Use of high-resolution NWP rainfall and river flow forecasts for advance warning of the Carlisle flood, north-west England. Meteorol. Appl. 16 23-34.

Roberts N.M and Lean H.W 2008: Scale-selective verification of rainfall accumulations from high-resolution forecasts of convective events *Mon.Wea.Rev.* 136 78-97

Tang Y et. al. 2011: *In progress*