Weather Prediction for the Road Industry

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ABSTRACT

The quality of any road forecast is crucially dependent on the accuracy of the meteorological data used in its preparation. Here we review the strengths and weaknesses of current numerical weather prediction models which are at the heart of most modern forecasting systems. The opportunities and challenges presented by the next generation of very high resolution models are also discussed.

Keywords: Numerical weather prediction   Resolution   Clouds

1.   INTRODUCTION

Numerical Weather Prediction (NWP) systems are central to most modern forecasting systems. Starting from an initial state (obtained by combining the output from earlier forecasts with recent observations in a process known as data assimilation) the models solve a set of equations to obtain an objective forecast of the future state of the atmosphere.

To solve the equations, models typically split the atmosphere into a series of grid boxes (or represent it through a number of spectral modes). The distance in the horizontal between neighbouring grid points, where the grid boxes intersect, is often referred to as the resolution or grid length (and the thickness of the layers in the vertical defines the vertical resolution). Motions on scales larger than this can be explicitly resolved by the model. The effects of smaller-scale motions and processes have to be simply represented or parametrized. Ideally the resolution should be as fine as possible (so that important processes are as far as possible resolved), but in practice what can be achieved is limited by available supercomputer power. Grid lengths in global NWP models have been coming down over the years, and are now typically in the range 20-60 km.

To obtain more detailed forecasts, it is common practice to additionally run higher resolution models over smaller areas (known as domains). These nested models receive data at their boundaries from the coarser resolution models, but can then provide extra information within their domain (e.g. showing the effects of hills and mountains not represented in the coarser models). It is possible for a whole sequence of models to be nested inside one another, each in turn using higher resolution but covering a smaller domain. As an example, Fig. 1 shows the current Met Office operational configurations. The global model has a resolution of around 40km in mid-latitudes, and drives a model covering the north Atlantic and much of Europe which has a resolution of 12km. Finally, a 4km resolution model runs over the United Kingdom. Additionally ensemble systems are run over the global and north Atlantic / European domains in order to give probabilisitc information.

In this paper we review recent progress with NWP models, their strengths and weaknesses, and some of the opportunities and challenges presented by future developments.

2. IMPROVEMENTS IN PERFORMANCE

Fig. 2 shows timeseries of the root mean square error in the northern hemisphere mean sea level pressure from a number of global forecast models. This statistic gives a good measure of the ability of the models to represent weather systems such as depressions. Although the skill of the various models differs, virtually all show improving performance in the 24 hour forecasts (left panel) over the last few years. These improvements come from a combination of improvements to the model resolution and formulation, and from better use of observational data. Errors in the 72 hour forecasts (right panel) are inevitably larger, but again a steady reduction in the size of errors from most models is apparent.
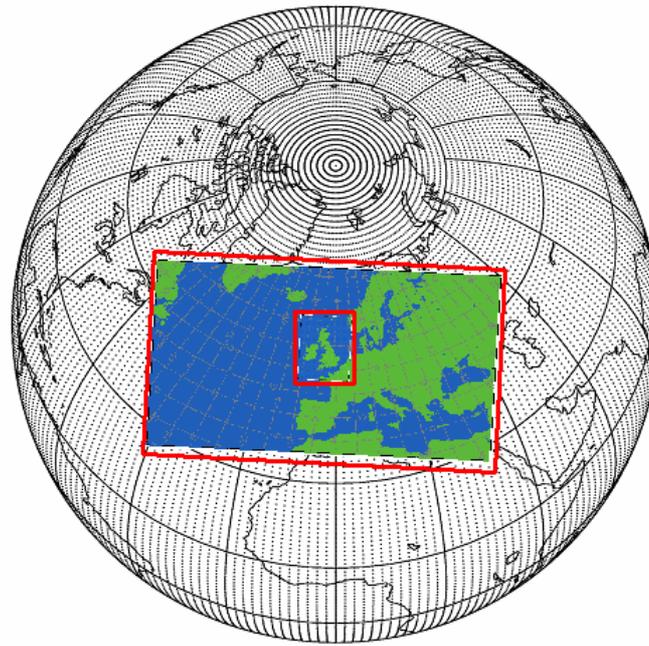
Fig. 1. Current Met Office operational NWP model domains.
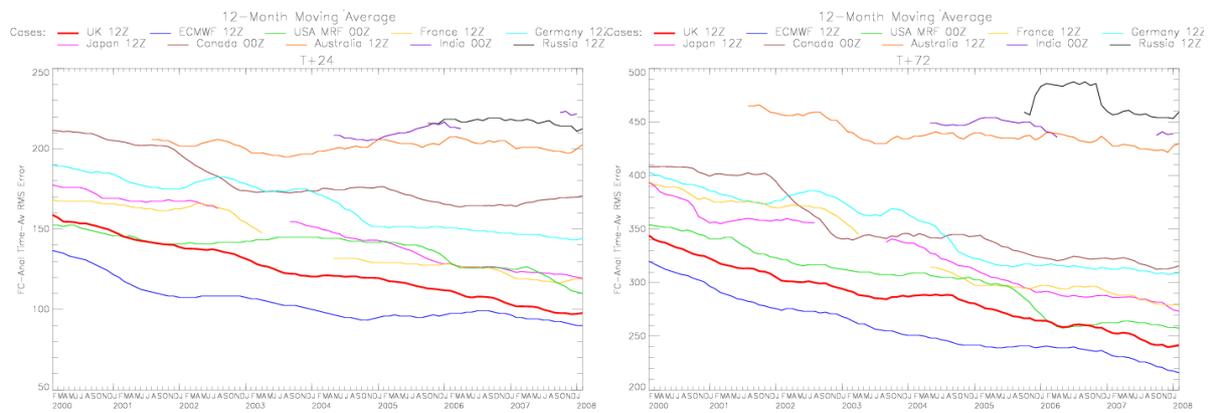
Fig. 2. Timeseries of root mean square error in northern hemisphere mean sea level pressure from a number of global forecast models. Left: 24 hour forecasts; right: 72 hour forecasts.
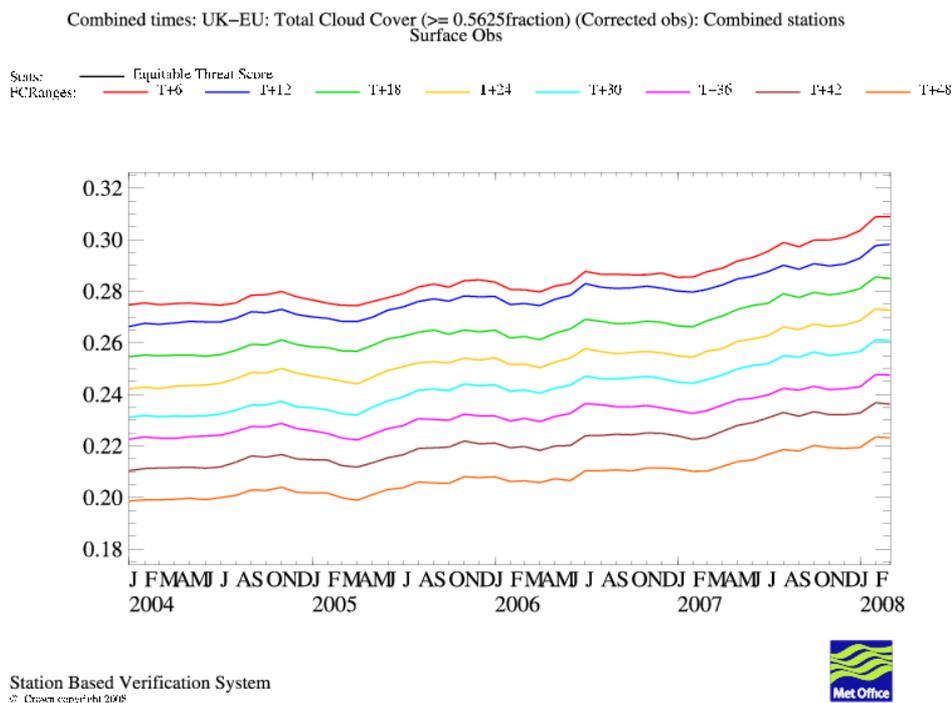
Fig. 3. Timeseries of equitable threat score for cloud cover greater than 5/8 at UK stations from the Met Office 12km model.

Performance for important weather parameters such as cloud and precipitation has also been improving. As an example, Fig. 3 shows the equitable threat score for fractional cloud cover greater than 5/8 from the Met Office regional model which uses a horizontal grid length of 12km. Performance at all forecast ranges has been improving, particularly in the last year. In fact the 24 hour forecasts in January 2008 were as accurate as the 18 hour forecasts in January 2007, and the 12 hour forecasts in January 2005.

In spite of these improvements in performance, it is as well to recognize that cloud prediction remains a challenging area for the models. This is particularly the case in anticyclonic conditions in winter in which patchy stratocumulus cloud is present in reality. In these situations accurate prediction of the location of cloud is likely to be critical to obtaining realistic forecasts of minimum road temperatures. However, this requires good observations and techniques to initialize the model, and an accurate model formulation to represent the cloud evolution. Poor vertical resolution may also hamper the ability of a model to represent thin clouds, and evidence for improved performance with improved vertical resolution is given in Section 3.3.

3. KILOMETRE-SCALE MODELS

As shown above, the results from global and regional models have been steadily improving over the years. However, even regional models with horizontal grid lengths of around 10km have some significant limitations. Accordingly many operational centres are experimenting with, or starting to use operationally, still higher resolution models. For example Deutscher Wetterdienst now run the COSMO-DE model over an area covering covering Germany, Austria and Switzerland with a horizontal grid length of 2.8km. The Met Office now uses a 4km grid length over the United Kingdom, and is developing a version of the model with a 1.5km grid length (and testing still higher resolution versions in research mode). This section gives examples of some of the advantages of using these higher resolution models, focusing on their improved ability to predict the development and movement of convective showers, and the increased local detail that they can provide. Finally it is shown how improving the vertical resolution of the model has recently proved beneficial for cloud and near-surface temperature forecasts.

3.1 Shower development and movement

Convective cells or showers clouds typically have horizontal dimensions ranging from a few hundred metres up to several kilometers. They are therefore too small to be explicitly represented in a regional model which has a grid length of around 10km. This means that their existence has to be predicted using schemes ('parametrizations') which attempt to represent what happens in reality between the model grid points. A feature

common to virtually all operational convective parametrizations is that they are equilibrium schemes which do not include memory from one model timestep to the next. This makes it very difficult for an unresolved shower to move from one grid point to the next (unless the cause of the shower is, for example, a trough line the movement of which can be explicitly modeled). With a 4 km grid length the largest convective systems are beginning to be explicitly represented and hence showers can start to be handled more realistically and moved from one grid box to another. Further improvements are gained at still higher resolution [3,4,6].
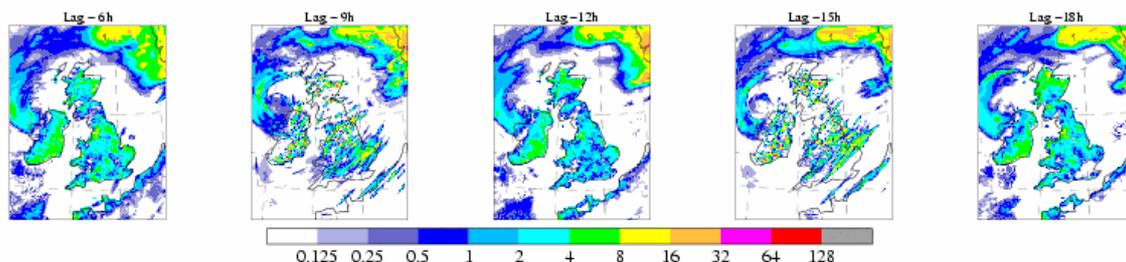
Fig. 4. Total precipitation predicted for 12UTC-18UTC on 17/07/2007 from successive forecasts. First, third and fifth panels: 12km model; second and fourth panels: 4km model.

As an example, Fig. 4 (courtesy of Marion Mittermaier) shows a sequence of successive forecasts, alternately from 12km and 4km models, for the accumulated precipitation between 12UTC and 18UTC on 17/07/2007. For this summer case, the 12km model consistently predicted precipitation over virtually the entire United Kingdom. However, as expected for a model with parametrized rather than explicit convection, the rain did not tend to move downwind (to the north east), and accordingly virtually none of the rain continued out over the sea. In contrast, the 4km results showed a pattern of streaks aligned south west to north east, corresponding to the passage of individual cells. Furthermore the rainfall associated with these cells did realistically extend out into the sea. Note that in winter improved ability to represent the movement of showers can be particularly crucial, as in this season they will often develop over the sea and then move inland before they decay – a process which is very poorly captured at 12km, potentially leading to significantly inaccurate forecasts of rain or snowfall.

Fig. 5 shows an example case study from 25/8/2005. This was IOP (Intensive Observing Period) 18 of the field campaign of the Convective Storms Initiation Project (CSIP) [1]. The figure compares satellite and radar results with those from a 1km resolution version of the forecast model. At this very high resolution the model is capable of realistic-looking producing cloud streets over the western parts of England and Wales. Downwind these develop into large convective cells, with precipitation patterns in reasonable agreement with the radar.

In spite of the advantages of these new models in terms of their ability to represent convective development, their use does present some challenges to the road forecaster. In particular, because of the detail and qualitatively reasonable output that can be obtained, there is an inevitable tempation to treat the output too literally. However, even if an area of showers is correctly forecast, it is unlikely that every individual shower will be correctly predicted. In future the predictability problem will be addressed to some extent by running ensembles of kilometre-scale models, but current computing power does not generally permit this to be done routinely yet. In the mean time, great care must be taken in the interpretation of the high resolution fields, particularly in any automated products [5,7].

OLR and Surface Rain Rate (mm/hr)
1130
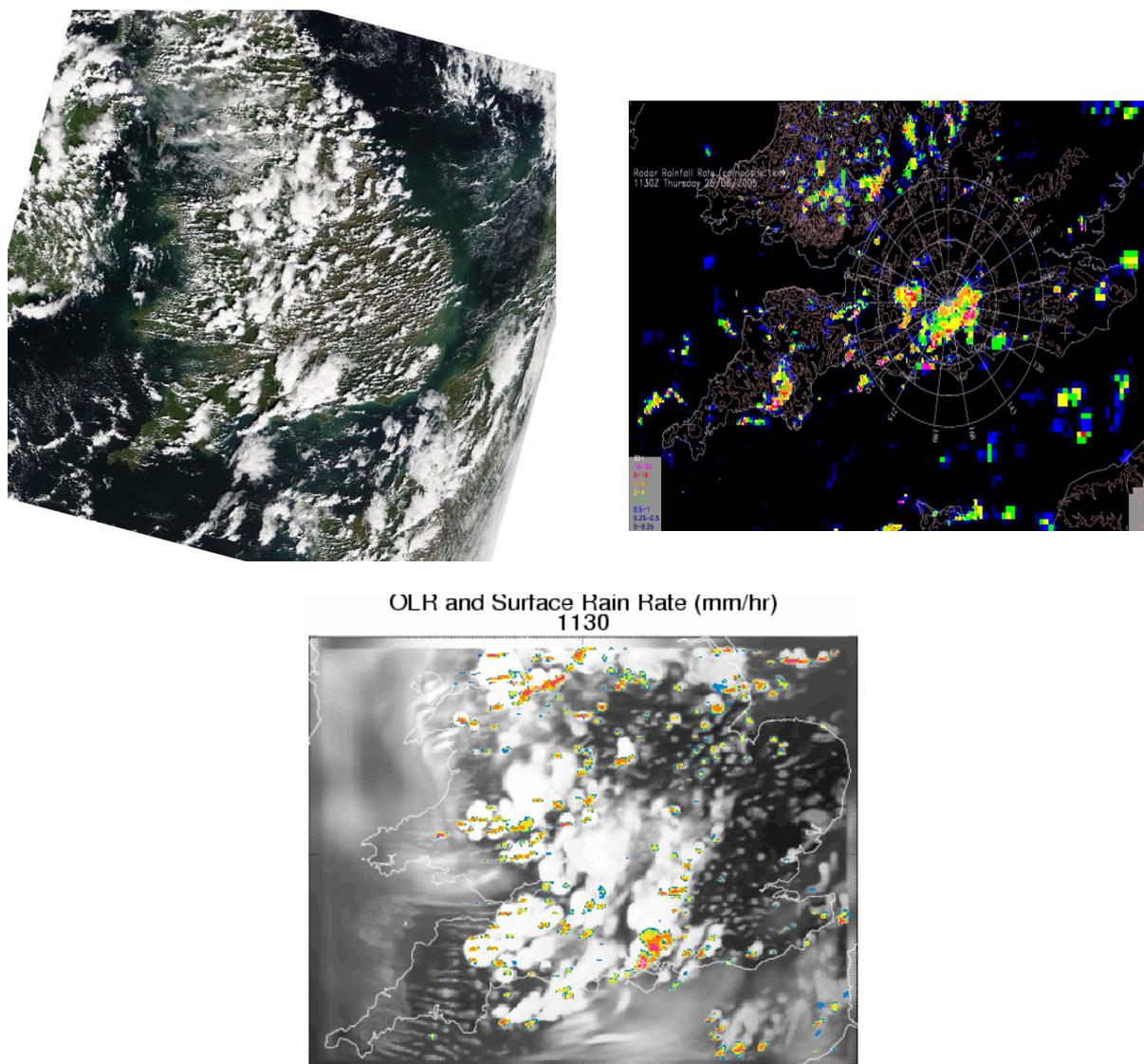
Fig. 5. CSIP IOP18 case study comparison with 1km model with satellite and radar. Top left: satellite picture; top right: radar; bottom: outgoing longwave radiation and precipitation rate from 1km model.

3.2 Improved local detail
Another major advantage of kilometre-scale models is their increased ability to represent local detail. This includes the heat island effects of towns and cities, coastal effects and the effects of local topography. All of these effects can give dramatic changes in local conditions on scales which will not be captured with coarser resolution models. This is particularly the case as the effective resolution of a numerical model will almost inevitably be coarser than the quoted resolution of the model – due to implicit smoothing carried out by the numerical schemes, and, in many cases, the explicit smoothing of the model topography relative to the numerical grid which is carried out to avoid numerical problems [2].

Fig. 6 shows an example forecast of visibility over southern England from the 12km and from a trial 1km model. The 12km model predicted low visibilities (100m or less) over much of the land. The results from the 1km model differ in two main respects. The first is a general tendency to predict higher visibilities. However, the second, which is the point we wish to emphasize here, is a much enhanced level of detail. The extra variability is strongly correlated with the much more detailed topography represented in the higher resolution model. For example, within the region of generally low visibilities, there are regions of significantly higher visibility (seen as blue regions within the predominantly orange area). These largely correspond to regions of high ground which protruded above the inversion and were hence clear of mist of fog (e.g. the line of the Chiltern hills

running from south-west to north east in the top right quadrant of the plot). Fig. 7 shows the root mean square error in the forecast of the logarithm of visibility for this case, and confirms that the results obtained with the 1km model are more accurate than those from the 12km model.
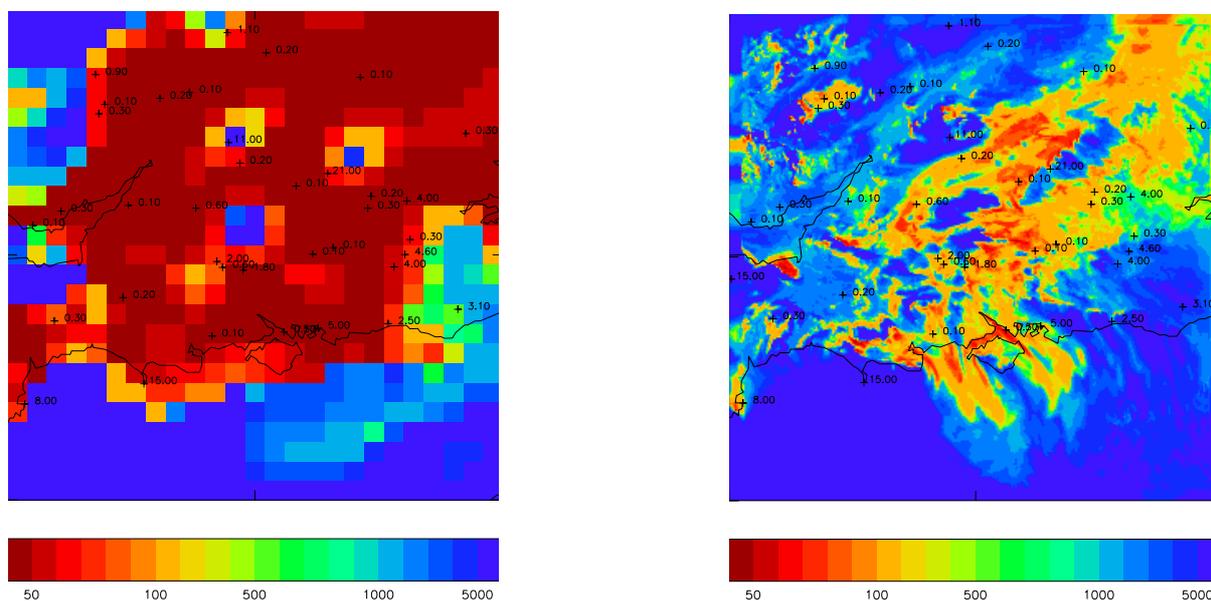
Fig. 6. Forecast visibility at 12UTC on 10/12/2003 in forecasts initialized at 18UTC on 9/12/2003. Left: 12km model; right: 1km model.
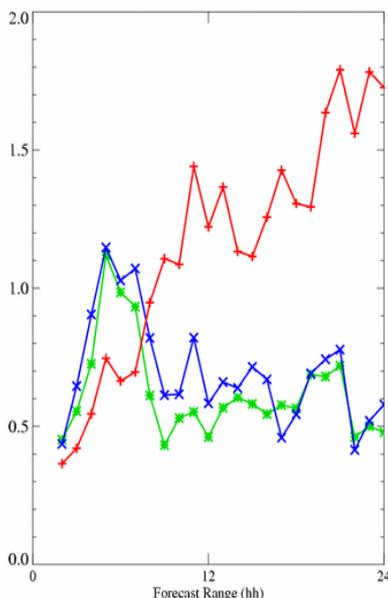
Fig. 7. Root mean square error in logarithm of visibility as a functions range for forecasts initialized at 18UTC on 9/12/2003. Red: 12km model; blue: 4km model: green: 1km model.

3.3 Benefits of higher vertical resolution

Fig. 8 shows the model levels used in the Met Office UK forecast model with 4km horizontal resolution before and after an upgrade in November 2007. Note in particular two aspects of the improved resolution when 70 levels are used:

- Reduced level spacing close to the ground, with the lowest model level now 2.5m above the local surface for wind and at 5m for temperature (compared to 10m and 20m with the old 38 levels). This allows of more accurate representation of the rapid variation of a temperature close to the surface on an extreme night with a very shallow stable boundary layer.
- Reduced level spacing higher in the boundary layer (e.g. around 100m instead of 250m at 1km above the surface). This gives a much increased chance of realistically representing thin stratocumulus sheets (with consequently improved surface and near-surface temperature forecasts).

Fig. 9 shows verification statistics from a month-long trial of the new 70 level model (UK-UK4 PS17). Compared to the 38 level control (UK-UK4 OPER) it showed reduced mean biases in both screen temperature and cloud cover (with that in the latter becoming close to zero). The root mean square errors in both fields were also significantly reduced. These results confirm that the anticipated advantages of using higher vertical resolution have been realized.
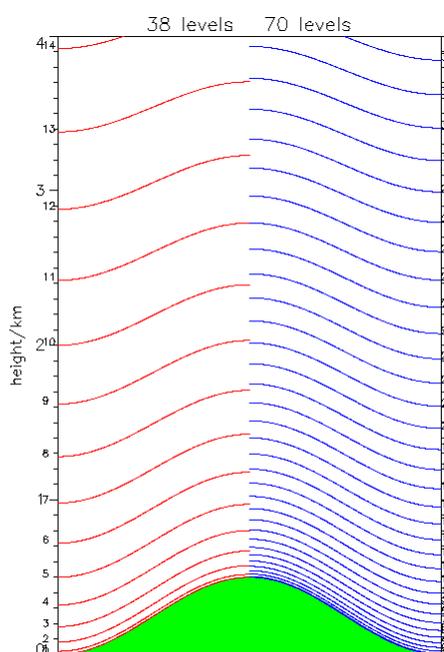
Fig. 8. Model levels in the bottom 4km of the 38 and 70 level versions of the Met Office 4km forecast model.

4. CONCLUSION

This paper has reviewed some of the progress made with NWP models in the last few years. The development of kilometre-scale models is particularly exciting, as they potentially offer the local meteorological detail which is crucial for route-based forecasting. It is likely that the use of these models will increasingly become the norm in the coming years.

In spite of the advances in NWP systems, it is important that the design of a road forecast system also recognizes their limitations. As noted earlier, while many aspects of the extra detail provided by kilometre-scale models are likely to be reliable (e.g. those linked to variations in surface height or character), predictability of convection remains an issue. Also obtaining accurate forecasts of the presence or absence of patchy stratocumulus remains a challenge (although moving to higher vertical resolution has helped). Discriminating between rain and snow in borderline situations can also prove troublesome. Nevertheless with advances in computer power and model formulation, we are confident that the next few years will see further significant progress made in these areas.
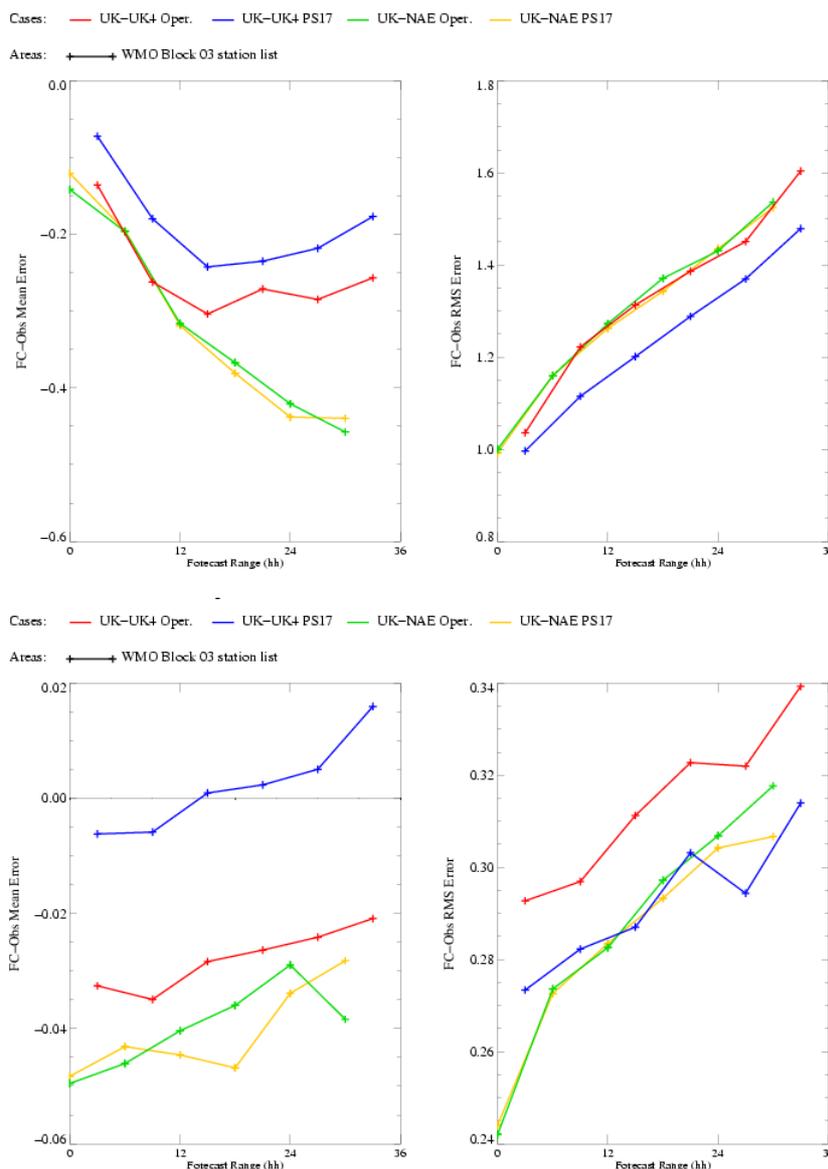
Fig. 9. UK verification statistics for 4km model with 38 levels (UK-UK4 Oper) compared to those with 70 levels (UK-UK4 PS17). The other two lines (UK-NAE Oper and UK-NAE PS17) show results obtained with two versions of the 12km model (both with 38 levels). Top: mean and root mean square screen temperature error (degrees); bottom: mean and root mean square cloud cover error.

5. REFERENCES

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