Nowcasting and high resolution forecast development
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1. Introduction

For the past 25 years the Met Office has had staff located at the Department of Meteorology, University of Reading. Much of this work has concentrated on mesoscale and convective scale processes, modelling and data assimilation. This led to the introduction of the UK4 and UKV forecast systems. This paper presents some of the more recent work on NWP-based nowcasting and high resolution forecast development.

2. NWP based Nowcasting

Forecasting over time periods of just a few hours ahead is commonly referred to as "nowcasting" and whilst the lead time is short, it can nevertheless provide useful information to the emergency response community which is especially important for prediction of potential pluvial flash flooding events and short response catchments.

Since March 2012 the Met Office has been running a demonstration trial of an hourly cycling Numerical Weather Prediction (NWP) system for southern UK. This combines a 1.5km resolution version of the Unified Model and 3km resolution 4D-Variational (4D-Var) data assimilation. This system is referred to as the Nowcasting Demonstration Project (NDP) and every hour produces analyses and forecasts for a period of 0 to 12 hours (6 hours when running on IBM P6 and 12 hours when running on IBM P7 from July 2012). Until acceptance of the IBM P7 in September 2012 the NDP was running on both the P6 and P7.

Ultimately it is hoped that a fully NWP-based system can replace the Met Office's current UKPP nowcasting system (Lagrangian extrapolation blended with NWP – either UK4 operational or UKV on trial) by combining an accurate depiction of the current weather with improved representation of the evolution and development of new weather and storm systems by using the full equations governing the behaviour of the atmosphere. Good data assimilation and analysis is vital for short period forecasts of 0-6 hours and frequent updates, using more recent observations of the state of the atmosphere, are needed.

2.1 The NDP forecasting and data assimilation system

The NDP is nested in the UKV model which provides it with lateral boundary conditions (lbc), but it produces 4D-Var analyses and forecasts every hour rather than 3D-Var analyses every 3 hours for the larger-domain UKV. The domain of the NDP, figure 1, covers just Wales and Southern England and the Midlands due to limitations of available computer power. By summer 2012 the domain contained 5 networked radars producing Doppler winds. The boundary conditions use 30min time interpolated output from the UKV which are refreshed when a new UKV run is available which was every 6 hours on the P6 and every 3 hours on the P7. This means that for instance on the P6 the 3UTC UKV is first used in the 6UTC NDP, the 9UTC UKV is first used in the 11UTC NDP, the 15UTC UKV in 18UTC NDP and 21UTC UKV in 23UTC NDP.

The NDP data assimilation time window runs from 30mins before the hour to 30mins after. We wait 15mins for observations to arrive so start the forecast at 45mins after the hour. The observation processing takes about 1 to 2mins, the 4D-Var analysis 3 to 10mins and the 12 hour forecast about 10mins on 6nodes of an IBM power 7 computer. The forecast is available approximately 1 hour after the nominal analysis time. The time taken by the 4D-Var depends on the number of observations - the Doppler radial winds (DRWs) are obtained by reflection of radar pulses from rain or ice cloud so there are more of these when there is widespread rain. It may be possible in future to have even more timely forecasts by having an off-centred data assimilation period of say 50 minutes before the hour to 10 minutes after the hour.
Up to now, operational NWP systems, such as the UKV, have typically used hourly or once per time window observations which may take 1-2 hours to reach the Met Office. The NDP requires sub-hourly data that need to reach the Met Office within 5-15 mins of the observation time so very fast processing and communication links are required.

The NDP currently assimilates:
- Doppler radial wind (DRW) observations from 5 radars, 6 times per hour,
- wind from wind profilers every 15 mins,
- satellite radiances from Meteosat Second Generation (MSG) SEVIRI channel 5 (clear and over low cloud) and channel 6 (clear) plus, over sea only, clear window channels every 15 mins,
- hourly 3D moisture derived from cloud observations (satellite + surface reports),
- MSG cloud and humidity tracked winds (AMV) once an hour, aircraft temperature and winds (AMDAR) once per hour,
- hourly surface temperature, relative humidity, wind, pressure and visibility.

In addition, radar-derived surface rain rates, available every 15 mins, are assimilated, in the first hour of the forecast, using the technique of latent-heat nudging – adjustments to the temperature and moisture fields aloft in response to the precipitation.

One difference from UKV is availability of radiosonde and hourly GPS data which arrive in time for UKV runs but not for NDP runs. Although occasionally some GPS data did arrive early. We now have access to near-real-time 15 min GPS data but this datastream wasn’t available in time for trialling and use in the NDP.

The UKV and NDP use the same control variables in VAR i.e. velocity potential, stream function, unbalanced pressure. However the UKV uses a new humidity transform whilst the NDP still uses total relative humidity. The reason for the difference is that the NDP uses background errors derived from NCAR Gen-BE software which allows calculation rather than just specification of lengthscales in the horizontal SOAR functions and the Gen-BE software had no code for the new humidity transform. The spreading functions applied to observations in the NDP are sharper than those in the standard UKV. For example, in the UKV the humidity spreading function has a horizontal scale of around 90 km whereas in the NDP it can be between 30 and 2 km depending on the vertical mode. This potentially allows the observational network to generate and retain

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Figure 1: Domain of NDP containing 5 networked radars with Doppler capability
sharper features in the NDP analysis and forecast. For more details see [http://www.metoffice.gov.uk/research/news/ndp-data-assimilation](http://www.metoffice.gov.uk/research/news/ndp-data-assimilation). New more flexible software has now been developed by the Met Office to calculate background errors for the Met Office Var system which will allow the new humidity transform to be tested in the NDP and has been used to produce new shorter lengthscale background errors for trialling in the UKV.

The NDP also doesn’t currently use the vertical adaptive grid used in the UKV (Piccolo and Cullen 2011 and 2012) as it had not yet been modified or tested in 4D-Var.

### 2.2 Example of an NDP forecast

![Figure 2: Surface rainrate at 15UTC (16BST) on 28th May 2012. NDP T+5 (top left), UKV T+12(bottom right) and current UKPP nowcast system T+5(bottom left) with the radar derived surface rain rate (top right).](image)

The NDP and UKPP forecasts shown in figure 2 are 5 hour forecasts from 10UTC and the UKV is a twelve hour forecast from 03UTC which is all that would have been available to the forecasters at the same time as the NDP and UKPP forecasts. The line of thunderstorms was not present at the analysis times for any of these forecasts. The UKPP blended nowcast failed to predict the storms as the extrapolation could not develop them and the operational 4km resolution UK4 forecast (used in operational UKPP) also did not develop them. The UKV 1.5km resolution forecast for the UK did develop some storms but they are too far east and isolated. The NDP has benefitted from a later analysis time, the hourly cycling, more observations and the more advanced data assimilation system of 4D-Var rather than 3D-Var and has a good indication of the line of thunderstorms and their location. When GPS data was included in the NDP, although the line of convection was retained, the forecasts did also get the spurious convection to the east of the line seen in the UKV forecast.
Other cases can be seen at [http://www.metoffice.gov.uk/research/news/nowcasting-demo](http://www.metoffice.gov.uk/research/news/nowcasting-demo) and the collaboration server [http://collab.metoffice.gov.uk/view](http://collab.metoffice.gov.uk/view) has some movie loops.

### 2.3 Performance during summer 2012 flooding and London Olympics

Although the original aim was to have the NDP running during the London Olympics since we started real-time running in March 2012 this meant we were able to assess performance during the extensive and numerous flooding and severe convection events in May to August 2012. Objective verification is only just starting so here we summarise some subjective views of the performance of the system.

- Some very good forecasts in centre of domain of thunderstorm development with improvement on UKPP, UKV
- Location of convection very much (too much?) tied to high ground in many cases
- Some poor forecasts where erroneous UKV lbc forecast was made worse in NDP
- Forecasts of large scale, long period, static, flooding events near boundaries are very similar to UKV
- Need to improve simulation of precipitation, cloud and convection in UM so that less patchy/blobby – will improve forecasts and DA
- The UKV provided a good 10 hour forecast of a line of convection causing flash flooding and rail disruption. However this structure was lost in the 4 hour UKV forecast and the hourly NDP forecasts so detrimental effect from data assimilation
- UK4 often missed isolated convection events, it was poor on summer convection so UKPP similarly poor
- For NDP size domain T+7 forecasts onwards were often very similar to UKV lbc forecast
- Need better treatment of GPS data in variational analysis for isolated convective events.
- Possibly too much consistency from run to run. Might expect location of convection to be random and perturbed by initial conditions but it seemed to remain fixed in successive runs as in the case shown in figure 2.
- Spurious bands of precipitation produced near boundaries when lbc updated to new UKV forecast eased by merging old and new lbc files during assimilation window.

It is clear that we need a larger domain not just to capture flooding events in the whole of the UK but also to get greater impact from the hourly 4D-Var data assimilation. Key issues moving forward are whether this can be the same system as provides forecasts to 36hours, whether a blended extrapolation forecast will always be needed for the first couple of hours to more closely match the observed distribution of rainfall and the dependency of the accuracy of the nowcasts on the synoptic scale forcing from the boundary conditions.

The accuracy of the nowcasts also critically depends on the skill of the underlying forecast model and so research is needed to improve the representation of convection either through improved parametrizations or higher resolution.

Improvements to the data assimilation scheme and the use of more novel observations such as volume scan reflectivity, ceilometer backscatter or radar derived refractivity or insect winds should also provide benefits. Improvements to cloud assimilation and moisture assimilation are still required to avoid spurious precipitation. Improvements to the linear model, moist control variables and inclusion of hydrometeor control variables are needed for the direct assimilation of reflectivity and other observations affected by cloud and precipitation. We still require flow dependent background errors and possibly a better representation of vertical velocity and convergence in the analysis increments. Improved treatment of vertical and horizontal spreading of information related to boundary depth and stability is likely to be required, for instance in assimilation of GPS data and other single level or column integrated moisture dependent observations in convective regimes.
3. High Resolution Forecast Development

3.1. Introduction
We now describe work being carried out to develop and improve high resolution forecasts. This includes work to improve and better utilise the existing 1.5km models and also work on higher resolution configurations. The work on higher resolution configurations is being carried out both to improve current 1.5km forecasts (for example the representation of convection) by understanding trends of model behaviour with gridlength and secondly to investigate the capabilities of high resolution forecast systems which will inform decisions about their future implementation and uses. The high resolution forecast development work falls into three categories which are now described in turn but focussing mostly on the work on improving the representation of convection.

3.2. Convection
Errors in the representation of the convection in the model can lead to significant errors in forecasts, as mentioned in section 2.3 above. The 1.5km models suffer from convective cells often being too large and too far apart and there being too much heavy rain and not enough light rain, an example of this is shown in figure 3.

![Figure 3: An example of rainfall field from the UKV model (left) compared to radar 15 UTC 12th April 2012.](image)

In addition the initiation of convection is often delayed and the models can sometimes miss very shallow showers altogether. Examination of the vertical velocity field, in particular, in the 1.5km models often shows a good deal of undesirable gridscale structure which is removed in higher resolution configurations. These issues are assumed to be due to the fact that, although convection is allowed to take place explicitly in these models, it is still under-resolved. Calculating of the average size of convective cells from the radar composite leads to the conclusion that they would only be marginally resolved at best in a 1.5km model. Various more idealised studies have suggested (Bryan and Rotunno 2005) that gridlengths of around 50m are required to adequately resolve deep convection. We also know from experience that the character of convection depends greatly on the configuration of the model (in particular the mixing/diffusion). It is clearly of importance to find out how to do the best we can at 1.5km and explore what the benefits of higher resolution might be.

3.2.1 Modelling
Initial investigations of resolution dependence of explicit convection in the UM have been made with a suite of nested models with gridlengths 4km, 2.2km, 1.5km, 500m, 200m and 100m all centred on the Chilbolton radar. For initial tests the domains of these models were kept reasonably small (the 100m domain was 800x800 points). The models were simply run as a nested set with no additional data assimilation with each model downscaling the next larger one. Essentially the same
configuration was used for all the models with all models (except the 4km) having no convection parameterisation. The main difference, aside from simple resolution dependent changes such as timestep, was that the 500m and finer models used 3d Smagorinsky mixing as opposed to 2d Smagorinsky plus boundary layer mixing. The high resolution model configuration was initially based on the configuration pioneered at 100m for investigations of the COLPEX experiment, see section 3.4. Using this set of models a number of convective cases have been run. An example of the output is shown in figure 4.

The 100m and 200m models tend to look much more like each other than like the other models. This is, however, likely to depend a great deal on the details of the mixing used in the model. For example a test with models at gridlengths of 500m, 200m and 100m showed that, as would be hoped, they can be made to look much more similar by keeping the mixing length constant across them rather than scaling with gridlength as usually used in the Smagorinsky turbulence parameterisation. An important issue which was found at an early stage of this work is vertical resolution in the models. Initial tests with the nested model set used the same 70 levels in the vertical as are used in the operational models. However it was found that 140 levels produce significant benefit in the 100m and 200m models in reducing the very small scale structure in the precipitation field. Investigation of this showed that the reason was that small scale boundary layer circulations are more vigorous and more prone to be precipitating in the 70 level model.

3.2.2 The DYMECS Project

The modelling work needs to be informed by observations. DYMECS (DYnamical and Microphysical Evolution of Convective Storms) is a collaborative project between Reading University (PIs Robin Hogan and Bob Plant) and MetOffice@Reading. The key concept is statistical evaluation of the properties of convective cells over 40 cases using data obtained using the Chilbolton radar in Southern England. In order to make the observations, code has been developed to track convective cells using Nimrod radar data and use this to steer the Chilbolton radar to scan one or more cells of interest. The data gathered can be used to derive macrophysical properties (cell size and cloud top height), microphysical properties (rain rate, mean drop size, hail intensity and cloud ice water content) and dynamical properties (turbulent kinetic energy and where possible the vertical velocity and momentum flux), all as a function of the time into the cell lifecycle.
Currently the field part of the project is coming to an end (40 cases have been observed) and the analysis and modelling phase is ongoing. An important goal is to attempt to constrain the vertical velocity and mass flux from the observations. The vertical component may be estimated by integrating the observed convergence of the radial wind either from the surface (ground-up) or from the echo-top (top-down), where the vertical velocity is assumed to be zero. This technique also requires that the cross-axis convergence is negligible. To evaluate the validity of this assumption and the choice of boundary conditions, this technique has been applied directly to 1.5km model output both with and without the inclusion of the cross-axis convergence. The resulting errors in the estimated vertical wind field can be evaluated, allowing an optimised average of the top-down and ground-up approaches (which are most accurate near the cloud-top and the surface respectively). Understanding these estimation errors, informs us as to how the observed distribution of vertical velocities extracting from the radar RHIs differs from the true distribution.

3.3. Convective Scale Predictability
A frequent source of error in forecasts of convection from the current 1.5km models is errors in the large scale fields imposed on the model by the driving model. This, not unexpected, result was confirmed by work on a number of high impact convective cases from 2011. This problem is being addressed by the 2.2km downscaling MOGREPS-UK ensemble. The ensemble approach also addresses the fact that small scale convective features (such as individual showers) are inherently unpredictable on the timescales we wish to forecast so we need to move to probabilistic diagnostics. Due to the small scale unpredictability on the convective scale and the fact that relatively small changes in the position of synoptic features represent large displacements on the convective scale, the 12 members of the ensemble would be insufficient to give smooth probability fields. In order to address this problem a fuzzy neighbourhood technique has been used to smooth the probability fields. These diagnostics were used in the MOGREPS-UK Olympic demonstration which is described in another paper. A subject of research is the possibility that the length scale used to smooth the probabilities can be set according to the spread of the ensemble by using a FSS technique to estimate the spatial scale of the differences between members. Convective scale predictability and its relationship to larger scale predictability is being investigated in collaboration with university scientists as part of the DIAMET (DIAbatic METeorology) project. We also plan to increase the scope of the work to include predictability aspects of visibility and low cloud as well as precipitation. It is expected that convective scale ensemble techniques will also be more frequently used as a tool in model process studies.

3.4. Urban Modelling
A 100m UM configuration has successfully been used in association with COLPEX (COLd Pooling Experiment) looking at night time cold pooling in small scale valleys in Shropshire. Following on from this we have started some work to investigate potential 100m configurations for urban modelling. The motivation for this work is to investigate what benefit might be obtained from running urban models on this scale as well as to more generally increase our knowledge of these UM configurations. This work is being carried out in collaboration with observational work being carried out in Reading University in association with other universities on the ACTUAL (Advanced Climate Technology: Urban Atmospheric Laboratory) and ClearfLo (Clean air for London) observational campaigns.

The initial tests have involved simply moving the COLPEX model configuration to London. This model has a 30x30km inner 100m domain (140 levels in vertical) with a variable resolution region outside. The model has been run for a number of cases including two clear sky summer heat wave cases. The preliminary results indicate that the model can give reasonable results with expected inhomogeneities in, for example, surface temperature being present with parks and the river being cooler during clear sky daytime conditions.

There are a number of issues which have arisen with this model. Firstly in cases with a convective boundary layer the boundary layer attempts to represent overturning explicitly but probably does not do this correctly although in at least one case the magnitude and depth of the updrafts appear
to be reasonable agreement with upward pointing lidar data. In one case where there is a significant wind the vertical velocity field organises itself into rolls near the inflow boundary which subsequently break up. In another with much less wind the vertical velocities form into a cellular structure. These structures are probably not realistic and in the first case are probably a boundary artifact. Another feature seen in these models, compared to larger scale models, is a tendency to form very sharp boundaries in the temperature field – it is not known if this is realistic. As well as these immediately noticeable issues there are important theoretical questions arising from the fact that the gridlength of the model is approaching the sizes of the buildings. All these issues are the subject of ongoing research in collaboration with university colleagues.

4. Future Plans

Future work at MetOffice@Reading will include research to include more novel observations such as radar reflectivity, radar refractivity, ceilometer backscatter and high resolution AMVs (cloud tracked winds) in convective scale data assimilation. We will also be carrying out collaborative research to improve high resolution models and inform future choices for forecast configurations such as horizontal and vertical resolution, domain size, ensemble size, assimilation methods and observation usage. Some of this will be informed by field campaigns and collaborative research projects such as DIAMET and COPE (Convective Precipitation Experiment).

References

