JP1J.9 ASSIMILATION OF RADAR DATA IN THE MET OFFICE MESOSCALE AND CONVECTIVE SCALE FORECAST SYSTEMS

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1. INTRODUCTION

The Met Office is developing a high resolution NWP forecasting capability with the aim of ultimately replacing existing nowcasting techniques. A 4km resolution model for the UK has been introduced operationally this year and the aim is for a 1km resolution system once sufficient computer power is available. This is based on the nonhydrostatic unified model (Davies et al 2005).

The 4km model is currently being run once a day without data assimilation using interpolated 12km resolution analysis/forecast as the initial conditions. A data assimilation system is under development for use at 4km and 1km resolution.

Radar data and satellite imagery are important sources of observations for high resolution modelling. Currently surface precipitation rate analyses derived from operational radar data are exploited operationally in the 12km UK and 12km North Atlantic and European forecast systems via latent heat nudging. Other data is analysed using 3D-Var and then the analysis increments are nudged into the 12km resolution forecasts along with latent heat increments derived from forecast/analysis precipitation rate differences and humidity increments derived from forecast/analysed cloud cover differences. Doppler radar radial winds outside the UK are assimilated via VAD profiles in 3D-VAR.

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The complete 3D-Var and nudging system has been trialled at 4km resolution and the nudging system using the 4km 3D-Var analysis increments and its own latent heat and moisture increments has been trialled at 1km resolution. These trials have shown the importance of the rain rate and cloud cover analyses in forecasts of precipitation, which is an important end-use of the system for flood prediction/ warning. Work is under way to test use of higher time frequency precipitation (every 15mins compared with hourly) and cloud cover analyses (every hour compared with 3 hourly) and to reduce overprediction of precipitation in the very short range forecasts.

The Met Office should have its first operational doppler radar radial wind products by the end of the year. VAD profiles from the first radar will be included in the operational analyses after monitoring to test the quality of the data.

Code to assimilate Doppler Radar radial winds directly has been incorporated into the Met Office Variational Data Assimilation system. The code has been tested using data derived from a PPI scan by the Chilbolton Advanced Meteorological Radar. The very high resolution raw data from Chilbolton is averaged (or "superobbed") to model resolution before assimilation. The project with the Chilbolton data is being carried out as a collaboration between the Met Office and a team at the Telford Institue of Environmental Science, Salford University (Dr. F. Rihan and Prof. C. Collier). Work is underway to ingest the operational radar data when it is available and to develop quality control and monitoring systems as well as operational systems to specify observation error and perform superobbing.

Projects in other groups at Reading University are also just starting to investigate the potential use of radar reflectivity and refractivity data in high resolution data assimilation systems. These are at an early stage concentrating on issues relating to the observations themselves. Other projects are looking at techniques for inclusion of precipitation data, and also reflectivity data, in the variational analysis system itself. Work is underway to enhance the linear physics in the perturbation (linear) forecast model 4D-Var system.

This paper describes the work being undertaken at, or in collaboration with, the Met Office to exploit radar data within the mesoscale and convective scale data assimilation systems.

2. SYSTEM DESIGN

The Met Office has undertaken initial trials of a high resolution forecast system based on one-way nested versions of the non-hydrostatic version (Davies et al 2005) of the Unified Model (UM). 4km and 1km gridlength versions of the UM centred over the southern United Kingdom were nested in the 12km mesoscale version of the UM which for a number of years has covered an operational area just larger than the UK. The model configuration is described in the companion paper by Lean et al (2005)

3. TRIALS

In order to evaluate a possible operational system 6 hour forecasts were run at all three resolutions at 3 hour intervals over the period of interest in each case. The 12km model was rerun as well as the 4 and 1km ones in order to provide boundary conditions for the 4km domain and also to enable statistical comparison of the current model with the new high resolution ones. The 3 hour cycle length was chosen for convenience since that is the length currently used in the operational 12km model. It is recognised that a real operational system at high resolution may benefit from a shorter cycle length.

A number of options were run including spinning up the 4km and 1km forecasts every cycle from the 12km T+1 analysis and running continuous cycles at 4km and 1km. Section 4 discusses the assimilation options used in the models.

4. INITIAL DATA/ DATA ASSIMILATION

A key question with high resolution models is how to provide initial data. The simplest approach is not to attempt any high resolution data assimilation but simply to start each forecast from a lower resolution analysis (12km in this case). This method has been used by many workers and was the only approach used in the early stages of this project. It was also used in the current work in order to produce control runs against which to compare the runs with assimilation. The obvious disadvantage of this technique is that the 4km and 1km forecasts take a finite time to spin up high resolution structure (around two hours). Since the period of interest in these forecasts is only out to T+6 this represents a serious reduction in the usefulness of the forecasts. For this reason a continuous system with high resolution assimilation has been set up to enable the high resolution structure from one forecast cycle to be propagated forward into the next.

The Met Office current operational 12km model uses an incremental 3D variational assimilation system (3D-Var) (Lorenc et al 2000) which generates a set of increments which are nudged into the model using an Incremental Analysis Update (IAU) scheme for an hour on each side of the nominal analysis time. These increments are constant in time and independent of the evolution of the model. The increments at each timestep being the total analysis increments divided by the number of timesteps in the 2 hour period. The 3D-Var includes surface temperature, humidity, pressure, winds and visibility, radiosonde, pilot and dropsonde data, satellite atmospheric motion winds, ATOVS radiances and wind profiler data with a time window of T-1.5 to T+1.5. The control variables are the same as in Lorenc et al 2000 with the addition of log(aerosol) for visibility assimilation and use of background errors derived from the difference of T+12 and T+24 forecasts from the operational mesoscale 12km United Kingdom domain. The length scales are specified using a SOAR function and uniform over the whole model domain and a horizontal transform based on double sine/cosine is used to enforce zero increments on the boundaries.

In addition the Moisture Observations Processing System (MOPS) provides fields of surface precipitation rates at 5km resolution and 3D cloud cover at 15km resolution derived from surface observations, radar and IR geostationary satellite imagery data via the NIMROD system. The precipitation data is reduced to 15km resolution and assimilated into the model via a Latent Heat Nudging (LHN) scheme (Jones and Macpherson 1997). The MOPS cloud data is converted to profiles of relative humidity and nudged into the model along with the latent heating increments using an Analysis Correction (AC) scheme. This nudging is carried out over a period either side of the analysis time which is T-2 to T+0.5 hours for the cloud and T-2 to T+2 for the precipitation (in the case of the latter this period overlaps with the period of nudging for the next cycle). The weights and values of these MOPS relative humidity and temperature increments vary in time and depend on the evolution of the model. The analysis is performed every 3 hours and uses 3 hourly MOPS cloud data and hourly MOPS precipitation data.

See figures 1 and 2 for schematic diagrams of the nudging and weights used in the 12, 4 and 1km resolution systems.

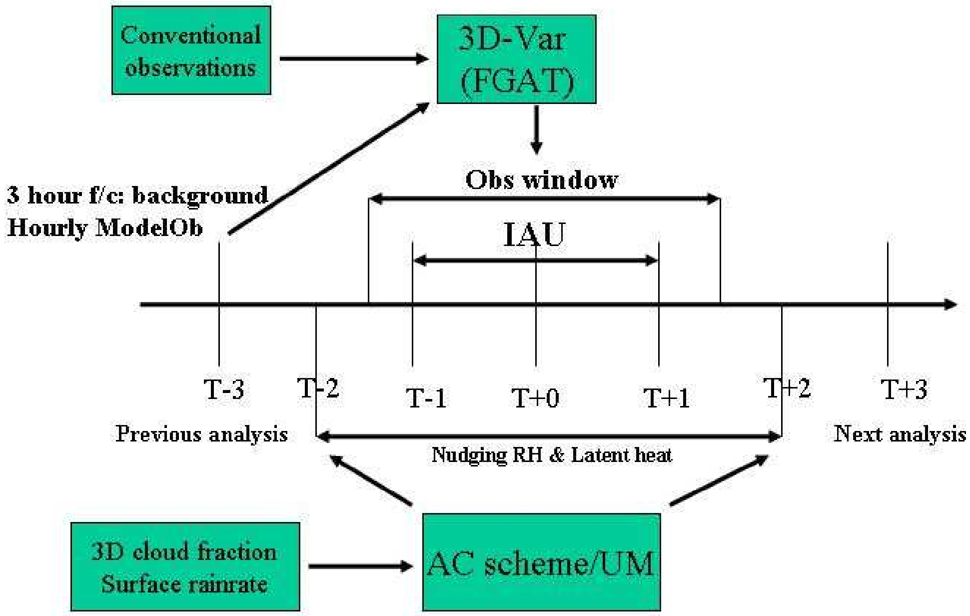

Figure 1. Schematic diagram of implementation of 3D-Var with initialization via IAU plus MOPS RH and latent heat nudging in the Met Office system at 12 and 4km resolution.

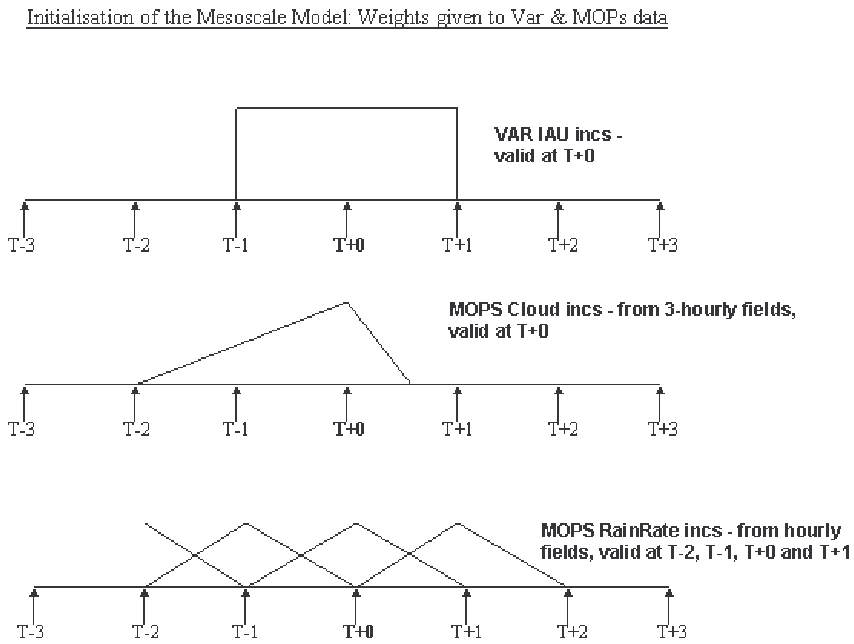

Figure 2 shows period over which observations and analysis increments are nudged into the unified model forecasts at 12km and 4km resolution.

In order to run the 4km model with assimilation the 3D-Var and MOPS/LHN systems have initially been taken over from the 12km model with few changes. There are improvements that could be made by tuning some of the parameters of the existing system (for example the error covariances or the correlation lengths and weights given to the MOPS data) as well as the incorporation of new sources of higher resolution data. Investigations with changes to the system used at 12km resolution will be discussed later. The MOPS/LHN scheme uses a search radius to find an appropriate latent heat profile of 6 gridpoints which is 72km at 12km resolution but only 24km at 4km and 6km at 1km resolution.

Initial trials were designed to evaluate the minimum benefits which might be obtained from continuous assimilation rather than an attempt to optimise the assimilation itself. It is important to realise that this technique does not add any new information on scales less than 12km so the high resolution information will still be self generated by the model. In future it is planned that extra high resolution data (eg radar, geostationary imagery and profiler data) will be assimilated into the model.

For the 1km model it was decided not to try implementing 3D-Var initially for a number of reasons. The first was to gain experience with using 3D-Var, MOPS RH and latent heat nudging at high resolution in a small domain with the 4km model first. The second was that it was straightforward to apply the background error covariances from the 38 level 12km resolution model in the 4km system but there was no experience in developing or using background error covariances on 76 levels. Thirdly was the cost implication of carrying out 3D-Var on 300x300 gridpoints and 76 levels and finally the potential problems of carrying out 3D-Var on such a small domain with a limited number of observations as no extra high resolution data was available.

Therefore as an alternative to spin-up from course resolution analyses it was decided to try to retain information from the high resolution forecasts by having continuous cycles of 1km resolution forecasts. One method would be just to update the boundary conditions with the latest 4km resolution forecast.

However in order to try to make some use of corrections based on recent observations it was decided to try making use of the analysis increments derived for the 4km resolution model and to interpolate them to the 1km grid and nudge them in over a period of 2 hours via the IAU system. This should provide some benefit if the 1 and 4km resolution forecasts remain similar on the resolutions resolved by the 4km model and enforced by the lengthscales in the 3D-Var system. If successful it would also save processing time. It is likely that the forecasts will diverge due to different resolutions, different surface characteristics and different parametrizations at 4km and 1km resolution. The fact that at 1km resolution the convection is resolved rather than partially parametrized at 4km resolution is likely to lead to differences in forecasts. However one would expect that since the 1km resolution forecasts are driven by 4km resolution boundary conditions that should force the forecasts to be similar on large scales.

The MOPS cloud and precipitation data can also be exploited at 1km resolution by applying the relative humidity and latent heat nudging. However the latent heat nudging scheme needed to be developed to allow it to work without the presence of parametrized convection so it was not available for initial trials on cases in summer 2003 but has been tested on summer 2004 cases and reruns of the 2003 cases .

5. RESULTS FROM TRIALS

The high resolution forecast system has been tested on cases of convective precipitation in summer 2003 and 2004.

The benefit of continuous assimilation compared to spinning up from a coarser resolution analysis or forecast can be seen in figure 3.

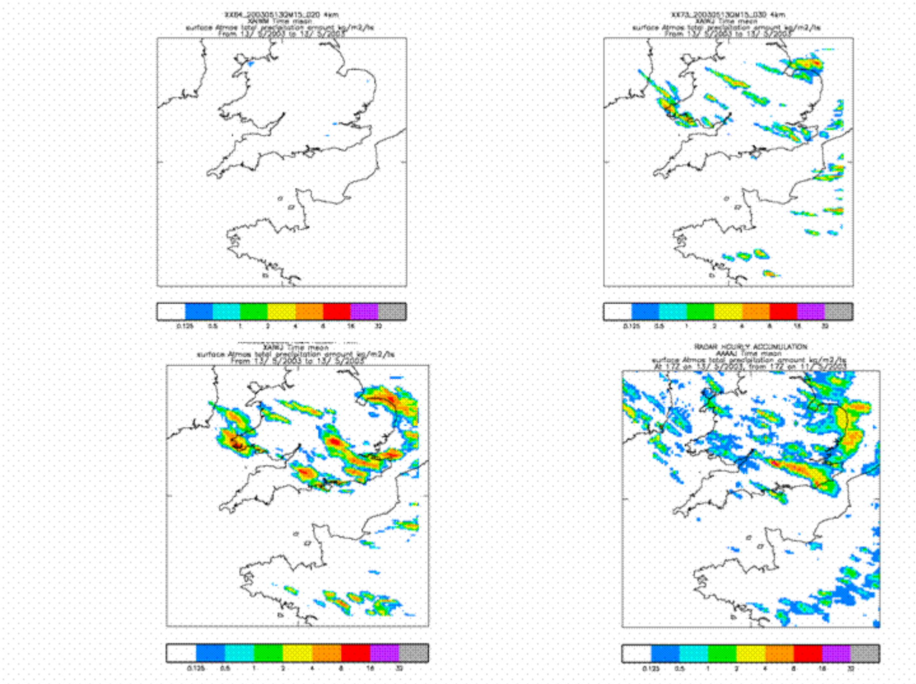

Figure 3. Precipitation amount (mm) from 16 to 17UTC for 4km domain for 4km resolution forecasts from 15 UTC 13th May 2003 . Top left is spun-up from T+1 12km forecast, top right is with 3D-Var only, bottom left is 3D-Var plus MOPS RH and LHN nudging and bottom right is radar data. All forecasts used diagnostic rain..

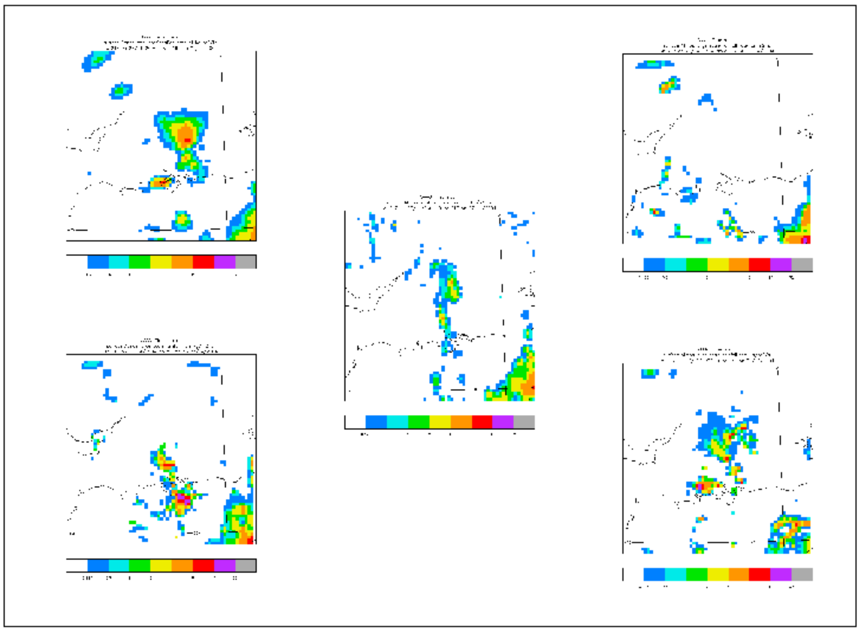

Figure 4. comparison of forecast precipitation rate with radar observations at 21UTC 27 April 2004. radar in centre & anti-clockwise from top left: 4km with MOPS/LHN; continuous 1km with MOPS/LHN (72 km search radius); 1km with MOPS/LHN using reconfigured 4km T+1; continuous 1km NO MOPS/LHN. All forecasts used diagnostic rain.

From figure 3 it can be clearly seen that the spin-up run has no indication of the precipitation at this early stage of the forecast. The run without MOPS data underdoes the precipitation amount although it does give a good indication of the distribution of precipitation. The run with MOPS data overdoes the precipitation amounts but there are some improvements in the distribution.

Some cases clearly show a positive benefit in terms of improvements in location of precipitation with use of MOPS humidity and latent heat nudging as can be seen in figure 4. The details of the forecast are sensitive to the forecast background and search radius in the latent heat nudging scheme. An increased search radius above 6km was required at 1km resolution in order to get impact from the MOPS data and 72km was used in the summer 2004 runs at 1km.

As discussed in Lean et al overall it was found that if no data assimilation was used in the 4km and 1km forecasts the model had very little convective precipitation in the first few hours of the forecast as the fields adjusted from parametrized convection to explicit convection. The model then overpredicted the precipitation peaking at about T+6. In runs including assimilation and MOPS humidity and latent heating the domain averaged precipitation was vastly overpredicted in the 4 and 1km resolution systems in the first 4 hours of the forecast whereas the 12km forecast produced values much closer to those observed by the radar. This is illustrated in figure 5 for the summer 2004 cases.

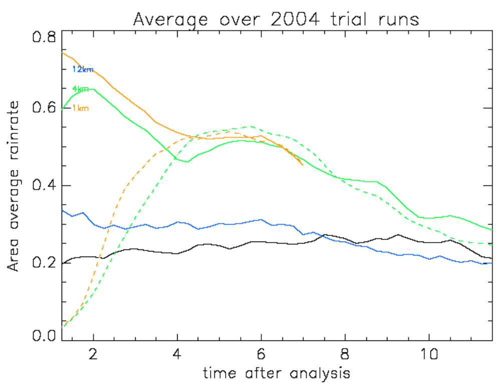

Figure 5. 1km domain averaged rain rates against time since forecast time. Black line is radar data, blue 12km model, green 4km and red 1km. Solid

lines are assimilation models and dashed models starting from 12km analyses.

For the summer 2003 cases which originally had no MOPS latent heat and moisture nudging at 1km resolution the forecast precipitation at 1km resolution was much closer to that from the 12km forecast as can be seen in figure 6. Reruns with MOPS included looked more like figure 5.

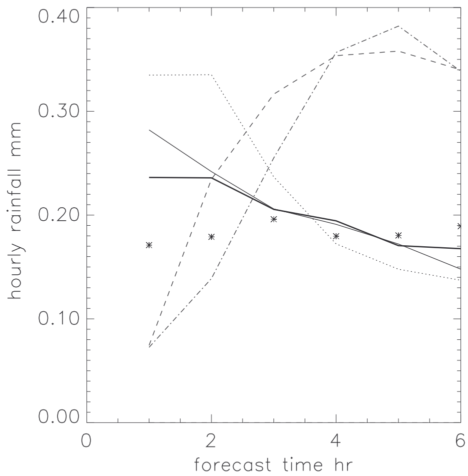

Figure 6. 1km domain area averaged precipitation hourly accumulations as a function of forecast time averaged over all 16 forecasts used in this study (i.e. four forecasts for each case) for summer 2003. Each point on the x axis represents an accumulation from the time to an hour later. The thick solid line is the 12km model, the dotted line the 4km model with assimilation and the thin solid line the 1km model with assimilation. The dashed line is the 1km model spinning up from each 12km analysis and the dashed dot line the equivalent 4km model. The stars represent the radar data.

Therefore further work is required to reduce the overprediction of precipitation amounts when the MOPS data is used in the high resolution models, especially when prognostic rain is included. In the 1km model it can cause spurious large scale circulations to develop either at the end of the nudging period or later in the forecast associated with the secondary peak at T+6 in figure 5.

6. SCALE SELECTIVE DATA ASSIMILATION

Application of 3D-Var on a limited area 4km resolution domain shows problems with analysis increments at the boundaries as increments are forced to go to zero at the boundaries and there is no influence from observations outside the boundaries. An attempt to improve this has been to modify the 4km resolution background by adding in the 12km resolution analysis increments filtered to scales greater than N km (N=180km seems to give reasonable results) and then analysing in the 4km resolution domain only scales less than N km.

The scale selective analysis allows the 4km fields to see some influence from observations at or outside the boundaries and appears to work well when the same data is used in both the coarse and fine resolution analyses. However it is likely to have problems if new sources of high resolution data are only used in the high resolution analysis as they won't be able to influence all scales of the analysis.

7. ASSIMILATION OF DOPPLER RADAR DATA

A program is under way to dopplerize some of the UK network of radars which will provide a vital source of data at high resolution. The observation processing system(OPS) and variational assimilation(Var) code has been extended to allow assimilation of doppler radar radial winds.

The code is being further extended to include quality control, superobbing and possibly a more sophisticated observation operator. The Met Office system will initially use a super-obbing strategy that averages innovations over a defined sector defined by radius and azimuth intervals and estimates an error for the superobservations based on the variation of the averaged innovations.

A project is also being undertaken with Salford University to investigate assimilation of radar radial winds using the Chilbolton research S-band radar data. Figure 7 shows the comparison of the radar observations for 12.15 UTC 1st July 2003 with a 7 hour forecast from the 1km resolution model for 13.00UTC. There is a slight timing error in the forecast but it can be seen that the model and observations compare well which indicates that it is sensible to try to assimilate the data. Salford University have been investigating alternative methods of superobbing and specification of errors.

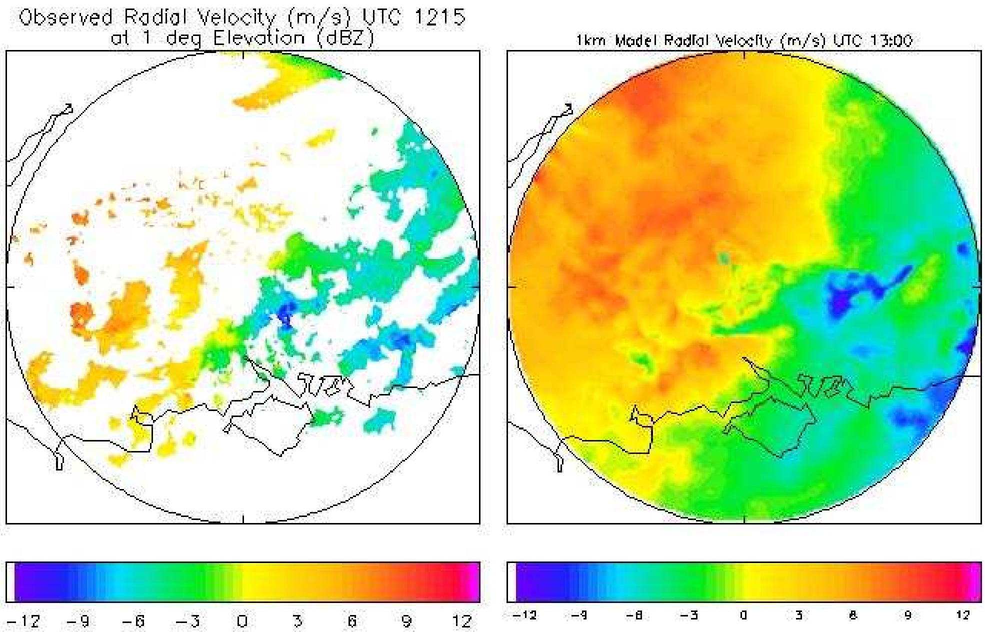

Figure 7 Comparison of Chilbolton radar radial Doppler winds for 12.15 UTC 1st July 2003 on left and model derived radial winds from T+7 forecast for 13.00UTC from 1km resolution model on right

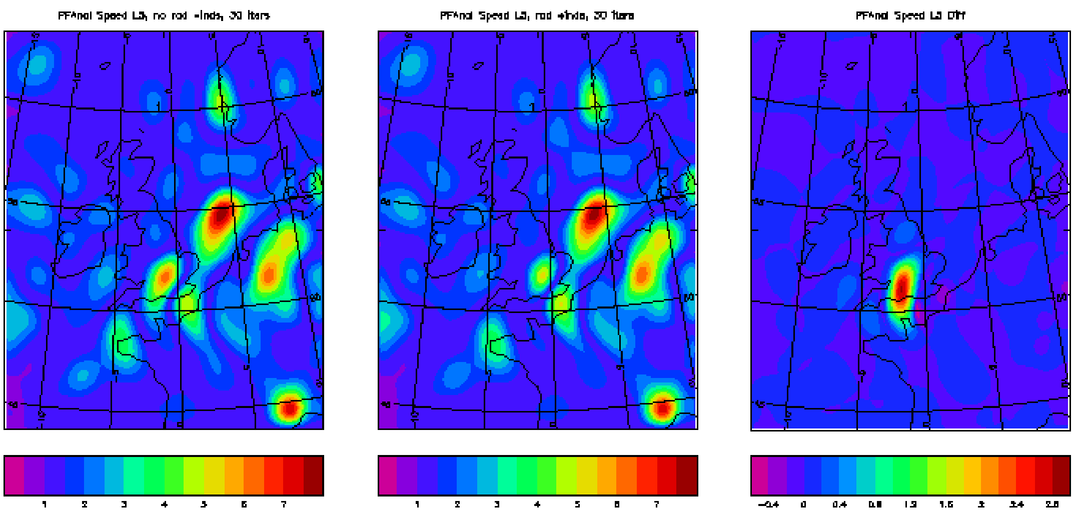

Figure 8 Wind speed increments from 12km 3D-Var on level 5 after 30 iterations at 12UTC 1st July 2003. Left with no radar radial winds, centre with radar radial winds interpolated to 5km resolution, right difference due to radial winds. One PPI scan for 12.15, shown in figure 7 included in the analysis

The doppler radar radial wind assimilation has been tested using the Chilbolton radar data for 12.15 UTC 1st July 2003 in a 3D-Var analysis for 12UTC 1st July 2003 at both 12km and 4km resolution.

The impact of the radar radial winds on the 12km 3D-Var analysis wind increments is shown in figure 8. Only one PPI scan at 12.15 UTC 1st July 2003 is available so there is no multilevel data. The radar data was interpolated to 5km resolution to provide some thinning/superobbing before inclusion in the analysis. Observation errors were specified by Salford University using a simple model dependent on distance from the radar. It is clear from figure 8 that there are other data in the same location as the radar winds and that the 2 data sources are implying different winds speeds, the radar data having lower values. This was investigated by producing the analysis increments for individual data sources as shown in figure 9.

It is clear from the analyses that there is a significant amount of airep data due to the proximity of the Heathrow Airport to Chilbolton. The aircraft descent and ascent data is providing wind increments across central southern England. This is likely to swamp any impact from the Chilbolton radar data and there appear to be biases between the implied wind speed increments from the 2 data sources. However the data may be on different vertical levels so that the overlap is occurring through the vertical correlations in the background error covariances and this needs further investigation.

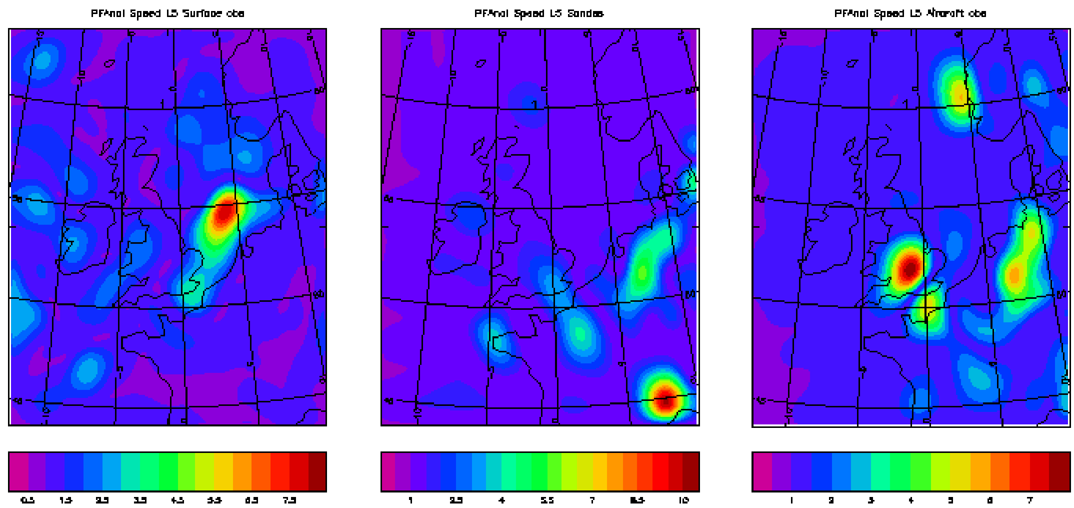

Figure 9 12km 3D-Var analysis wind speed increments on level 5 for 12 UTC 1st July 2003 from separate data sources. Left is surface synop observations, centres is radiosonde data and right is aireps 12km 3D-Var analysis increments of wind speed at level 5 for surface observations on left, sondes in middle and aircraft observations on right

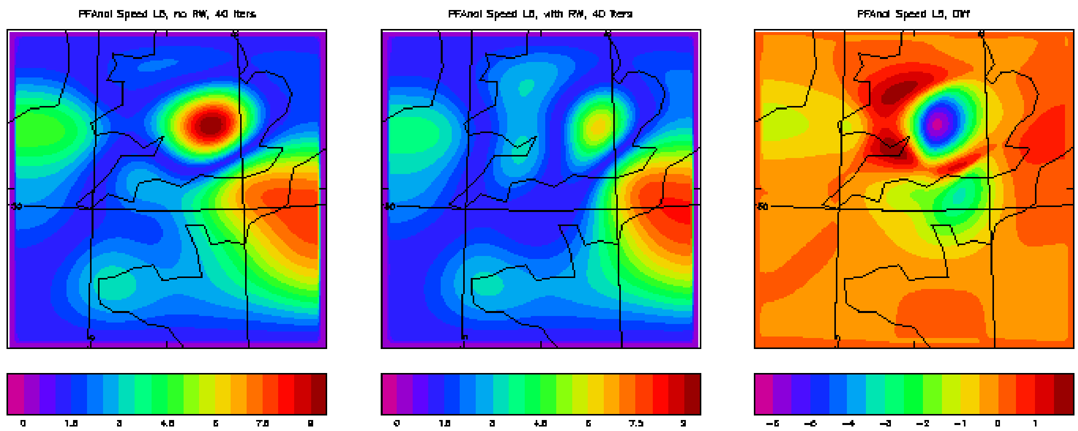

Figure 10 Wind speed increments from 4km 3D-Var on level 5 after 40 iterations at 12UTC 1st July 2003. Left with no radar radial winds, centre with radar radial winds interpolated to 5km resolution, right difference due to radial winds. One PPI scan for 12.15, shown in figure 7 included in the analysis

Figure 10 shows the 4km 3D-Var analysis increments of wind speed at level 5 from the standard analysis (including renormalization) with and without doppler winds (interpolated to 5km resolution).

Work is also starting in collaboration with the Satellite Applications group at Reading to look at other sources of high resolution data such as radar reflectivity, ground based profilers and radiometers and satellite imagery.

8. INVESTIGATION OF 4KM RESOLUTION 3D-VAR USING CHILBOLTON RADAR DATA

The Chilbolton radar data was used to investigate the performance of the 3D-Var analysis on the 4km domain.

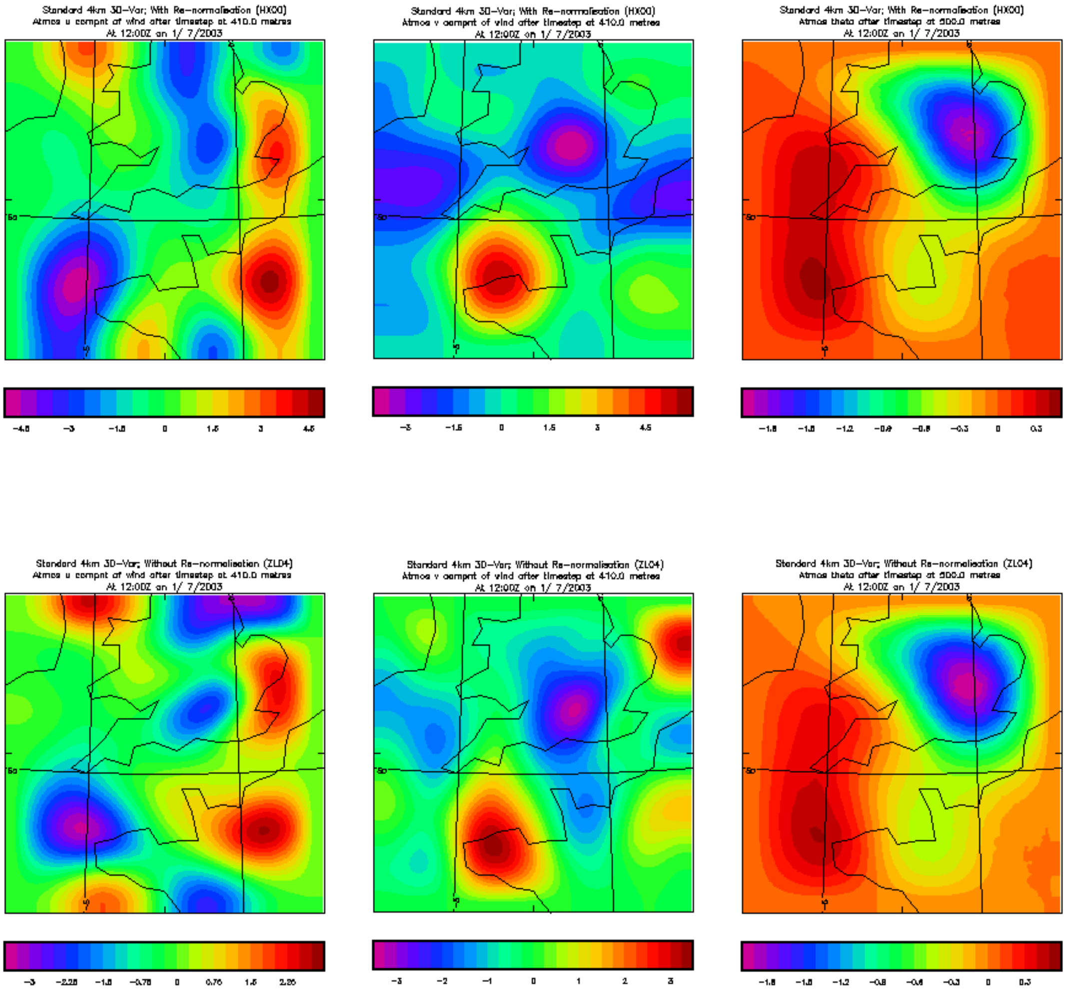

Figure 11. 3D-Var analysis increments at level 5 , approx 410m, for 12UTC 1st July 2003. u on left, v centre and theta right. Top row is with renormalization and bottom row is without

Figure 10 used the standard analysis with renormalization of horizontal variances turned on as is done in the standard 12km version of 3D-Var. However it has been found that using the renormalization increases the wind analysis increments in the 4km domain compared to those in the 12km domain using the same backgrounds, observations and background error covariances. Figure 11 illustrates the impact of turning off the renormalization on the analysis for 12UTC 1st July 2003 with the radar data excluded. This illustrates the fact that there is hardly any impact on the potential temperature analysis but that the wind increments are reduced without renormalization.

Figure 12 illustrates the impact of the change from standard analysis to scale selective analysis when radar data is included in only the 4km resolution analysis. In both cases renormalization of the variances is turned off unlike in figure 10 which included renormalization. The differences around the boundaries are due to the inclusion of the 12km analysis increments in the scale selective analysis. However for the v component of wind there is an additional interior change near the Welsh borders.

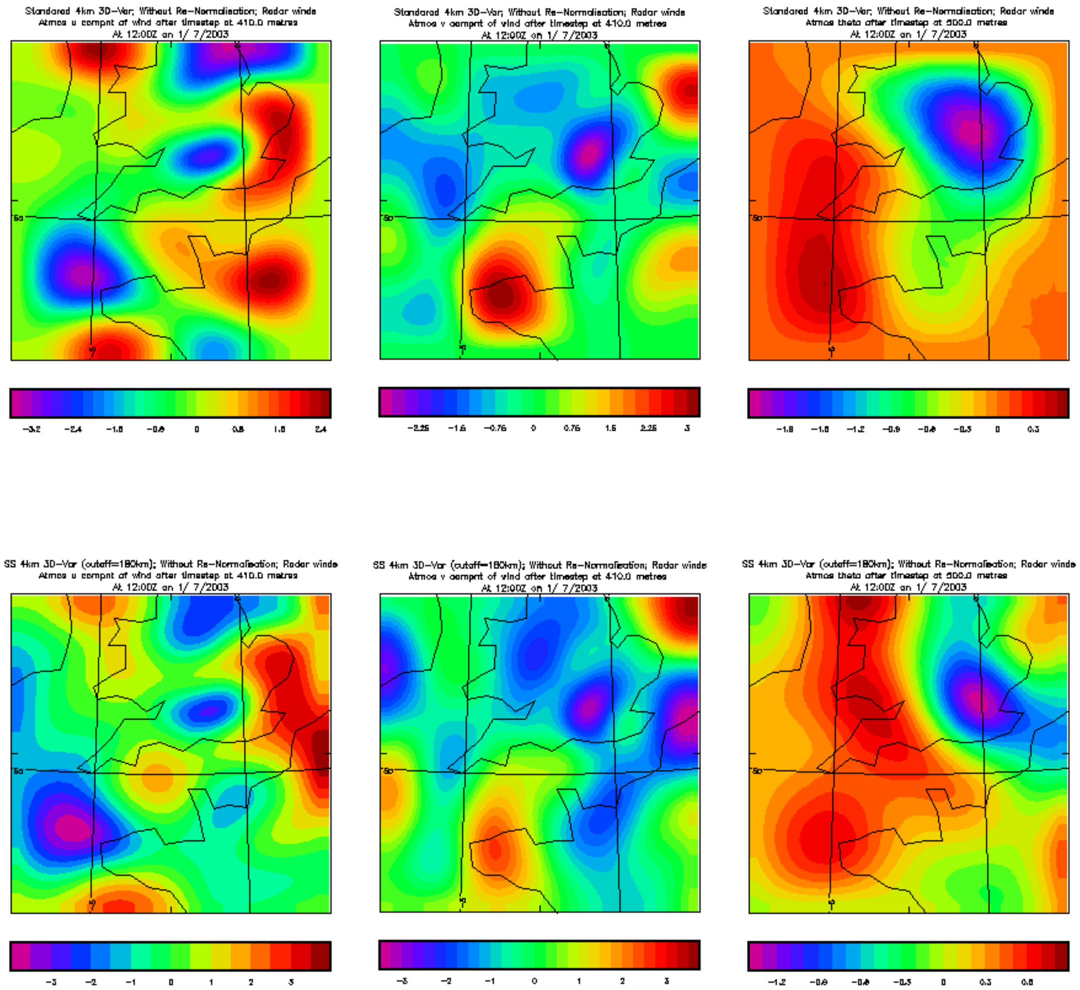

Figure 12. 3D-Var analysis increments at level 5 , approx 410m, for 12UTC 1st July 2003. u on left, v centre and theta right. Both rows are without renormalization and with Chilbolton radar data. Top row is standard analysis and bottom row is scale selective analysis with 180km cutoff with radar data only in the 4km analysis.

Figure 13 illustrates the impact of the 12.15UTC data on the analysis for 12UTC 1st July 2003 when the scale selective data assimilation with cut-off at 180km is used. The radar data is used in the 4km analysis but not the 12km analysis so that only the short wavelengths in the analysis see the effect of the radar data. The pattern of u increments is similar but with larger magnitude when the radar winds are included. The pattern of v increments shows shorter wavelength features and there is negligible impact on the potential temperature increments.

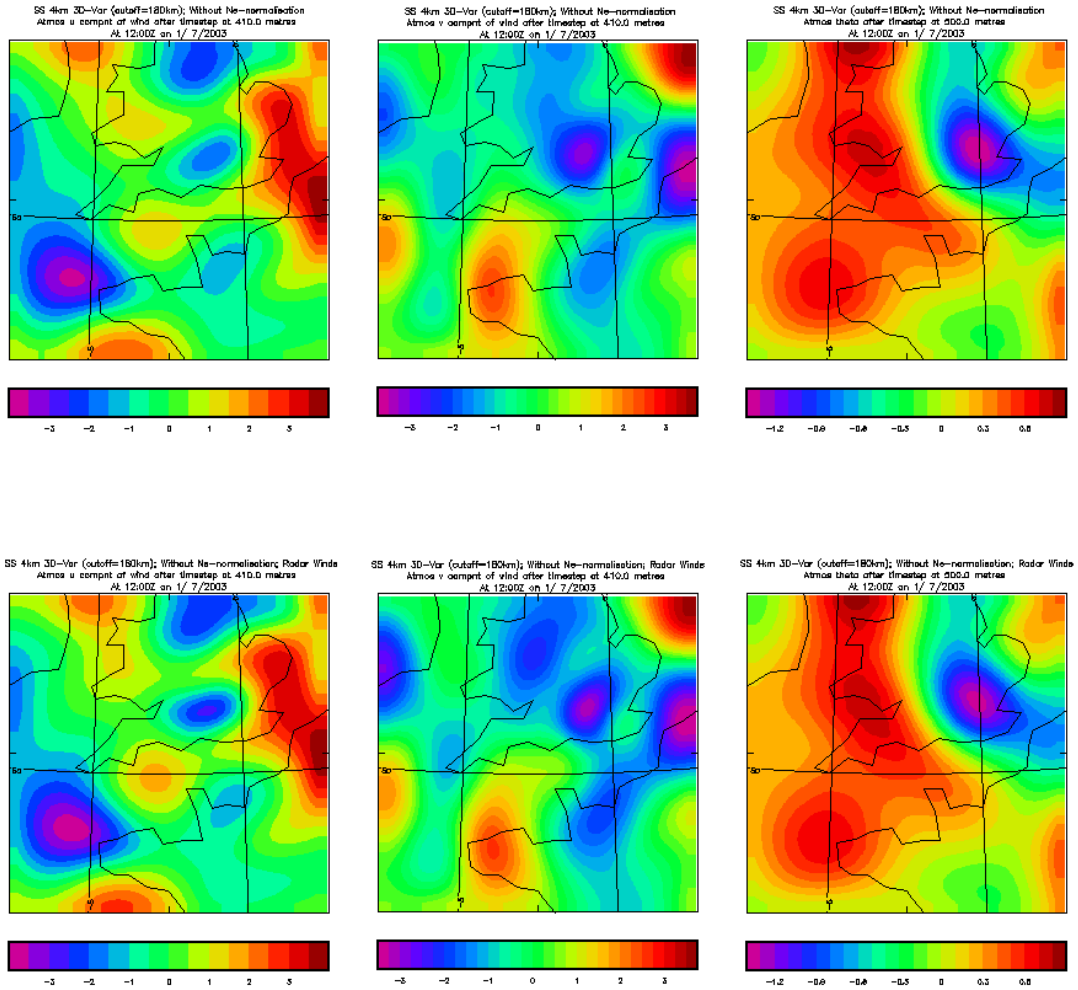

Figure 13. 4km 3D-Var analysis increments at level 5 , approx 410m, for 12UTC 1st July 2003. u on left, v centre and theta right. Both rows are without renormalization and with scale selective analysis with 180km cutoff. Top row is without Chilbolton radar data and bottom row includes Chilbolton radar data at 4km only.

Figure 14 shows the impact of the radar data in different analysis methods on the v component of wind. Using scale selective data assimilation with the radar data only in the 4km analysis cannot capture the full impact of the wind data. With data in the centre of the domain the 12km and 4km analyses are very similar. Scale selective data assimilation including the radar data in both the 12 and 4km analyses restores the full impact of the data.

It is clear from these results that we cannot see any structure in the analyses on the scale of the observations so that having the individual radial wind observations may not provide any advantage over use of VAD winds derived from the source data. We are investigating use of smaller horizontal correlation length scales to see if any meaningful structure is derived from the observations. The default lengthscales range from 90 to 180km depending on the control variable. It is 90km for relative humidity and log(aerosol), 130km for unbalanced pressure and stream function and 180km for velocity potential.

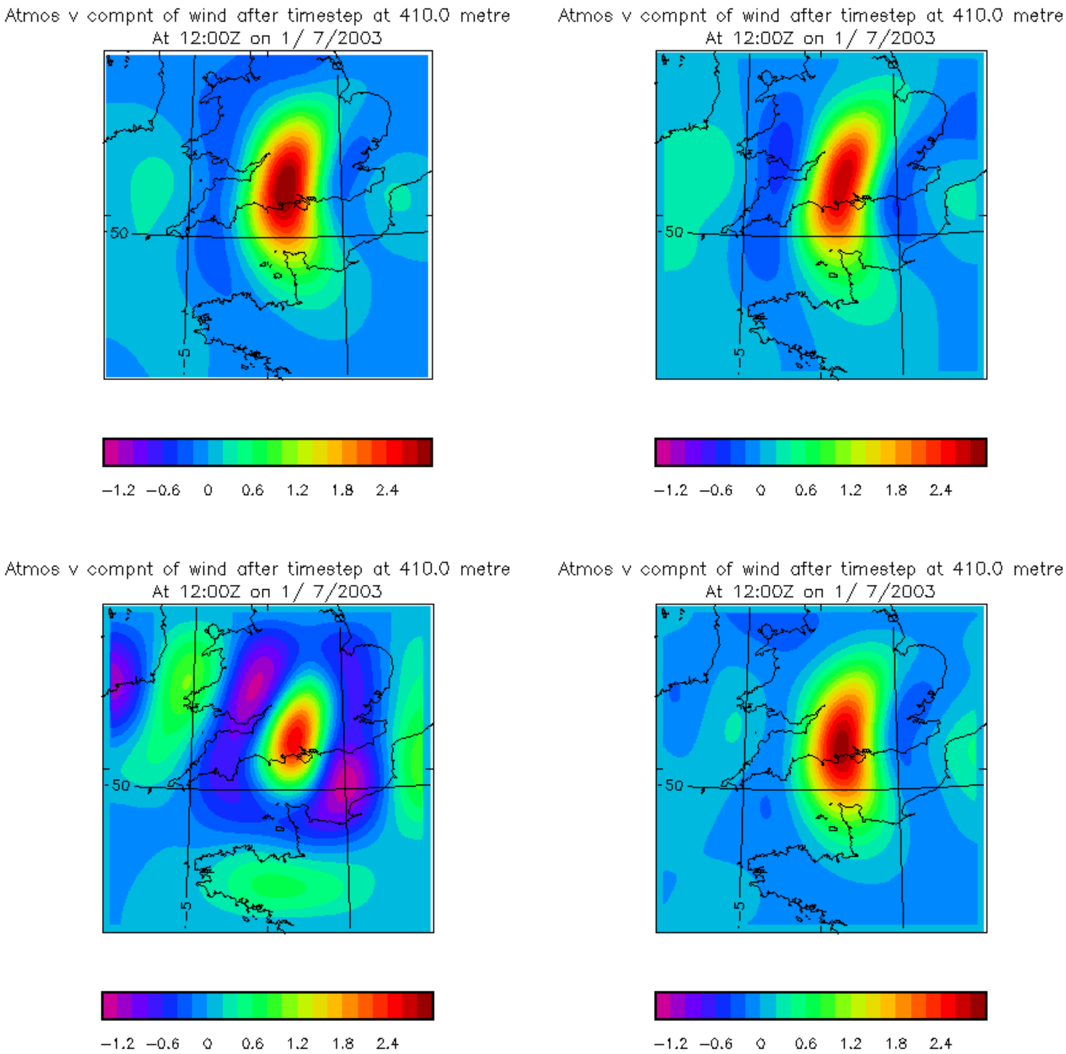

Figure 14. 3D-Var v analysis increment differences (radar – no radar) at level 5 , approx 410m, for 12UTC 1st July 2003. Top left is 12km analysis interpolated to 4km domain, top right is standard 4km analyses, bottom left is scale selective analyses with 180km cutoff with radar only in 4km resolution analysis, bottom right is scale selective analyses with 180km cutoff with radar data in both 12km and 4km resolution analyses

9. CONCLUSIONS AND FUTURE WORK

Initial trials of data assimilation for 4 and 1km versions of the unified model show the benefit of continuous assimilation over spinning up from coarser resolution forecasts for prediction of the location of precipitation in the early hours of the forecast. They also show some benefit from latent heat and moisture nudging in correcting the location of precipitation. However the amounts predicted are over forecast. In some cases with the latest version of the models including prognostic rain spurious large scale circulations can develop with significant areas of erroneous precipitation.

DWD (personal communication) have found problems with latent heat nudging in high resolution forecasts with prognostic rather than diagnostic precipitation. In our system the problem seems slightly worse when prognostic (as in figure 3) rather than diagnostic rain is used. Prognostic ice/snow has been used in the UM for a long time (Wilson and Ballard 1999) so may be causing problems in the basic system at high resolution. Latent heat nudging assumes that latent heating and precipitation are coincident. However once the convective circulations are resolved this is no longer the case. We are investigating whether latent heat nudging can be used successfully at high resolution by modifications to the scheme and use of higher time frequency data. Weights, smoothing areas and search radius may need adjusting for higher resolution. However it may be that at these resolutions latent heat nudging is no longer appropriate and we have to rely on moisture nudging alone.

Ideally we would like to move away from 3D-Var and nudging for cloud and preciptation data and use 4D-VAR to exploit the information in the time history of the observations and to provide a link to the full dynamics of the generation of the precipitating systems. This is unlikely to be affordable for a first operational system but work is underway to implement the physics required to enable assimilation of cloud and precipitation data within the Met Office 4D-Var system. A limited area 4D-Var capability is now available. We hope to test it at high resolution in the future.

In the meantime we will investigate use of 3D-Var within the 1km resolution forecast system, possibly at coarser horizontal and vertical resolution. It was clear from the trials that the 1km and 4km forecasts were diverging so it wasn't appropriate to use the analysis increments derived for the 4km forecast in the 1km resolution model.

Clearly there are some problems associated with the use of small area domains and the quality of the analysis near the boundaries and need to provide changes to the synoptic scale as well as convective scale. The technique we have used here will not solve the problem when extra convective scale information such as radar doppler winds are used only in the high resolution system nor when the high resolution assimilation is carried out more frequently (eg half-hourly or hourly) than the system providing the boundary conditions (eg every 3 hours). A variable resolution model is under development which would allow a larger domain with high resolution just centred on the area of interest. This brings in new issues for data assimilation. The plan is to use the variable resolution model for the initial observation innovations but carry out the variational analysis at a fixed resolution coarser than the target 1km resolution.

We have started work to exploit higher resolution observations starting with radar radial doppler winds. These should become available routinely from an operational radar for the first time in the UK in Autumn 2005. The assimilation system is being developed and tested on data from the Chilbolton research radar in collaboration with Salford University. It is clear that work may be required related to interaction with other high resolution sources of data such as AMDAR aircraft take off and landing data and the need to allow finer scale structure to be analysed by use of reduced lengthscales in the background error covariances. Work is also starting in the Met Office unit at Reading to enable use of high resolution geostationary imagery data and radar reflectivity data. Reading University are looking at the feasibility of extracting refractivity information as a source of low level humidity information from the UK operational radar network. Additional sources of data are higher time resolution surface observations and GPS data.

Radar data provide a good source of high resolution information for use in convective scale numerical weather prediction. It can provide information on location of surface precipitation and 3 dimensional reflectivity data provides information on hydrometeors, dopplerized radars can provide direct measurements of wind fields and refractivity data can provide information on low level humidity. From our initial experiments exploiting limited radar data in high resolution models it is clear that modifications are required to the data assimilation system and potentially the numerical weather prediction model to fully exploit that data (eg changes to include water loading and modifications to diffusion). We are building the systems to allow us to exploit that data within nudging, 3D-Var and 4D-Var systems and need further work on model formulation, background errors, control variable transforms (eg relaxation of geostrophic balance and inclusion of surface friction), weights and formulation of latent heat nudging to get full benefit from the data.

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