Proceedings of ERAD 2006

Assimilation of Doppler Radar Radial Winds

Sean J Swarbrick

Met Office JCMM, Reading, UK

1 Introduction - High Resolution Trial Model

The Met Office is developing a high resolution assimilation and forecast system based on the non-hydrostatic Unified

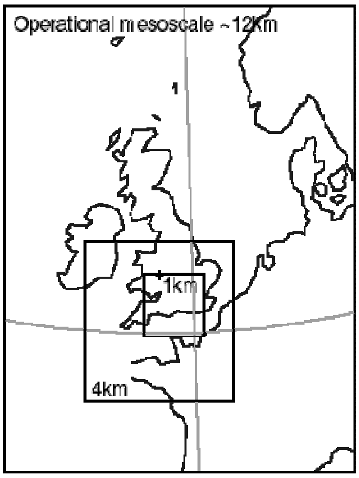

Fig. 1. Embedding of 1km, 4km, and 12km domains for high resolution trial model.

Model, see Davies et al. (2003). A trial system has been tested with a 1km model, whose domain is centered on the Chilbolton research radar in Southern England. This domain is embedded within a 4km model domain, which is in turn embedded within the 12km operational model domain. High resolution observations are required for assimilation into the high resolution model – Doppler radar radial winds are one such observation type.

2 Doppler Radar Radial Winds

The radial velocity (i.e. along the radar beam) of radar reflecting targets such as raindrops can be determined from the frequency shift of reflected radar pulses. Such radial wind measurements are usually obtained when the radar operates in Plan Position Indicator mode – performing 360 degree scans at fixed elevation. Elevation angle is typically 1-10 degrees and maximum range typically 100km.

3 Met Office Radar Network

There is a program to Dopplerise the UK. radar network. One Doppler radar is already available – at Cobbacombe in Devon. This will be followed by the Kent radar, and subsequently by others in the network. The operating frequency is 5.625GHz.

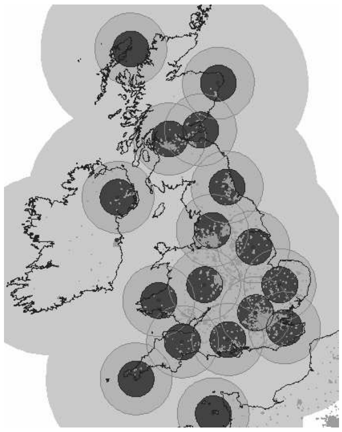

Fig. 2. Met Office radar network. Circles denote resolution of coverage – inner 1km, middle 2km, outer 5km.

4 Super-Observations

The horizontal resolution of raw radial wind observation data is around 300m. It is thus unsuitable for direct assimilation into NWP models because of correlations between observations, and because NWP models are unable to represent data on such fine scales. It is therefore necessary to average the observation data to a coarser scale. The

Correspondence to: sean.swarbrick@metoffice.gov.uk

averaged data are known as Super-Observations – see figure 3 for an example.

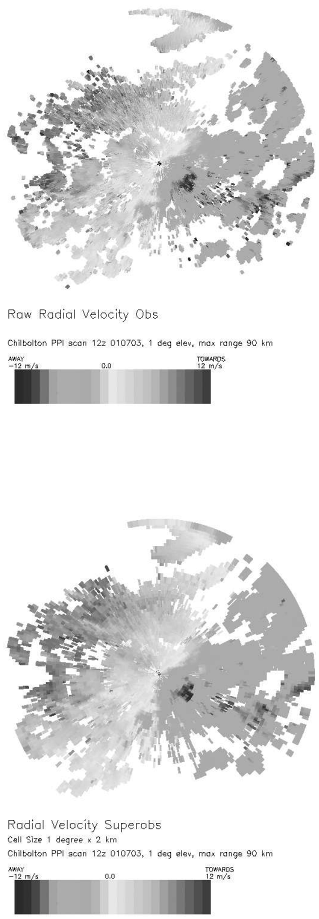

Fig. 3. Raw radial velocity observations (upper frame) compared with super-observations (lower frame). The resolution for the superobservations is 1 degree x 2 km. The wind direction is north-westerly.

The procedure by which superobservations are generated is based on Berger and Forsythe (2005) and is as follows. The PPI scan surface is divided into 2-d sectors, defined by radius and azimuth intervals which may vary over the domain. A model-generated background wind field is used to compute model-simulated radial winds. The innovation for each raw observation is computed by subtracting the simulated radial wind from the observed radial wind. The innovations are averaged on each sector and the result added to the model-simulated radial wind at the cell centre, to give the superob value.

The estimated error of each superobservation is also computed as part of the superobbing procedure. This is used for quality control and also by the assimilation system to weight the observation terms in the penalty function. In addition to the superobbing error it is also necessary to take into account the measurement error of the raw observations - see Miller and Sun (2003). Analysis of the source of measurement errors can be found in Nastom (1997).

5 Radial Winds and Variational Assimilation

Radial winds have been included as an observation type in the Met Office Variational Assimilation System (Var).

The Var system generates an analysis of the state of the atmosphere at a given analysis time by combining observations, lying within a time window around the analysis time, with a model background. The Var algorithm is formulated in an incremental manner – i.e, it is based on the departures of observations and analysis from the model background. The Var analysis consists of fields of increments which can be added to the model background to give the estimated state of the atmosphere. The procedure by which the observations and background are combined involves the minimisation of a Penalty Function. The penalty function (equation 1) is made up of a background term – measuring how far the Var analysed state is from the model background, and a number of observation terms – one for each observation type – which how far the analysed state is from the observations.

$$J = J_B + \sum J_{Oi} \qquad (1)$$

Each observation term J_{Oi} is computed by means of an "observation operator". The function of an observation operator is to calculate model estimates for observations. For each observation operator there is also an "adjoint operator", which calculates the gradient of J_{Oi}, required for the minimisation agorithm.

The observation operator for radial winds uses the following formula,

$$V_B = u\sin\phi\cos\theta + v\cos\phi\sin\theta + w\sin\theta \qquad (2)$$

where u, v, w are the wind components and φ, θ are the azimuth and elevation of the radar beam. The elevation angle includes a correction which approximately takes account of earth curvature and radar beam refraction. It does not yet take account of radar beam broadening.

Var has two modes of operation – 4D-Var, which takes account of the time-spread of the observations, and 3D-Var, which does not. So far, all experiments with radial wind observations have used 3D-Var only.

For more details of the Met Office 3D-Var system, see Lorenc et al. (2000).

6 Sample Results – 12UTC 1st July 2003 case

This case involved bands of convective showers moving south across Southern England during the day. Figure 4 shows the radar rainfall picture for 12UTC.

Radial wind observations from a single PPI scan from Chilbolton were available for 1215UTC. This was super-obbed to about 4km resolution, and estimated observation errors assigned.

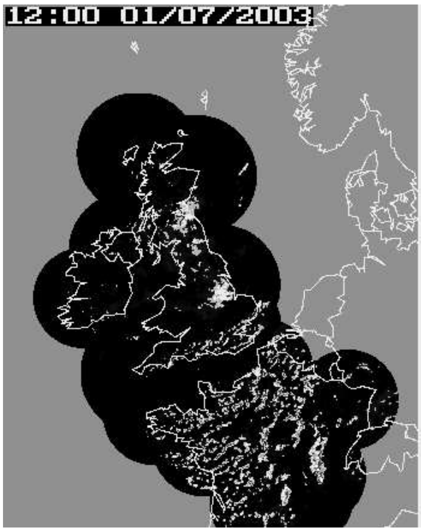

Fig. 4. Radar precipitation plot for 12UTC 1st July 2003

Assimilation experiments using 3D-Var at 12km and 4km resolution were performed. Each experiment used a number of observation types – surface, aircraft, and sondes, and also satellite winds in the 4km case. Anlyses were generated with and without radial winds observations and the results compared.

The impact of radial winds on the Var analysis is illustrated in figures 5 and 6. The plots show wind speed increments (derived from wind component increments) on model level 5. Level 5 is shown because it is at about half of the maximum altitude of the radar beam, which is about 1.5km. The signal from the radial wind observations can be seen in the difference plots. The 4km plot shows a more complex structure than the 12km one.

There is some conflict between the radar radial winds and the aircraft winds – there is a large amount of aircraft wind data due to the proximity of Heathrow to Chilbolton. This is likely to swamp any impact from the radial winds. The aircraft wind observations would be on different vertical levels than the radar winds, which implies that the conflict arises through vertical background error correlations.

UM forecasts were run at 12km and 4km resolution using the Var analyses generated in these experiments. The results showed little impact on precipitation forecasts – differences were seen only at the level of fine detail, not in the overall distribution. Note that this was a good forecast already, so the scope for impact from radial wind assimilation was limited.

The correlation length scales in the Var system may be too long to enalble the fine-scale radial wind observation data to have a significant impact of the Var analysis. Shorter correlation lengths may be required to to obtain benefit from such high-resolution observations.

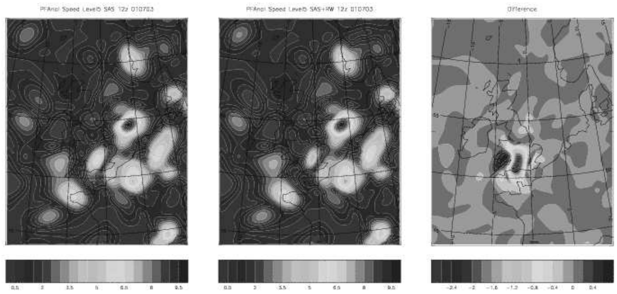

Fig. 5. Wind speed increments for 12km 3D-Var on model level 5. 1215UTC 1st July 2003. Left panel – assimilating surface, sondes, and aircraft observations only. Middle panel – as left but with radial winds included. Right panel – difference (middle – left).

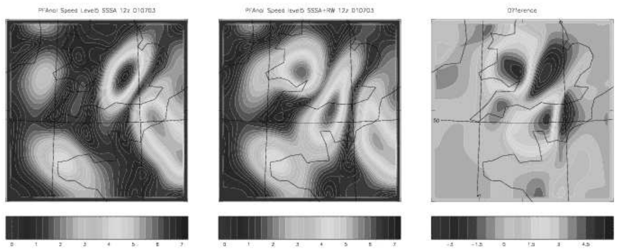

Fig. 6. Wind speed increments for 4km 3D-Var on model level 5. 1215UTC 1st July 2003. Left panel – assimilating surface, sondes, and aircraft and satwind observations only. Middle panel – as left but with radial winds included. Right panel – difference (middle – left).

7 Conclusions and Future Work

A basic package to assimilate Doppler radar radial winds has been incorporated into the Met Office Data Assimilation System. It takes in raw observations, performs quality control on them, averages them to yield "super-observations", computes estimated errors, and generates a Var analysis by means of a basic point-wise observation operator.

The error estimation algorithm requires improvement, as the errors computed currently may be unrealistic. A more sophisticated observation operator should also be developed, eg. one which takes account of beam-broadening.

More work is required to understand the impact of radial wind assimilation on high resolution forecasts, and their interaction with other observation types.

A fully automatic interface with the Met Office radar observation data base has yet to be developed (the data base itself is still under development).

References

Berger H., and Forsythe M., 2003, Satellite Wind Superobbing, Forecasting Research Technical Report 451, Met Office.

Davies T., Cullen M.J.P., Malcolm A.J., Mawson M.H., Staniforth A., White A.A., and Wood N., 2005, A new dynamical core for the Met Office global and regional modelling of the atmosphere. QJ Royal Meteorol. Soc., **131**, 1759-1782

Lorenc A.. et al., 2000, The Met Office Global 3 Dimensional Variational Data Assimilation System, Q. J. Royal Meteorol. Soc., **126**, 2991-3012

Miller L.J., and Sun, J., 2003, Initialisation and forecasting of thunderstorms: specification of radar measurement errors, 31st conference on radar meteorology, American Meteorological Soc., Seattle.

Nastom G.D., 1997, Doppler radar spectral width broadening due to beamwidth and wind shear, Ann. Geophysicae, **15**, 786-796.