Assimilation of Doppler radar data into Met Office Unified Model

Fathalla Rihan, Chris Collier and Sue Ballard

1 Introduction

Numerical Weather Prediction (NWP) is an initial-boundary value problem: given an estimate of the present state of the atmosphere, the model simulates (forecasts) its evolution. The goal of Data Assimilation (DA) is to construct the best of the Initial Conditions (IC), known as the analysis, from which to integrate the NWP model forward in time. The observations are typically irregular distributed in space and time, the DA involves deriving the best current state of the atmosphere by combining the model forecast background (the most recent information) with observations giving each a weighting which depends upon their characteristics.

Doppler radar uses electromagnetic waves to investigate atmospheric properties: the amplitude of waves are used to estimate the reflectivity and phase of the waves are used to estimate the radial wind. The radial velocity of scattering particles is determined from their observed phase difference between successive radar pulses.

Limited Area Models (LAMs) require observations with high spatial-temporal resolution to determine the ICs. Doppler radar has the ability to scan large volumes of atmosphere with high resolutions. It provides measurements of radial velocity and reflectivity with high resolution. Doppler winds give extra information in forecasting of quickly developing mesoscale systems. The resolution of radar data is however much higher than the resolution of the NWP models.

Assimilation of Doppler data into operational NWP models presents formidable scientific challenges. The aim of this project is to develop an incremental assimilation of Doppler radar wind data into UM using 3D-Var/4D-Var, leading to an improved representation of the Initial Condition (ICs) for storm-scale forecasting. Examine the impact of assimilating reflectivity combined with radial velocity data.

The data used are based on PPI volume scans (Each PPI- Plan Position Indicator-is taken at a single, fixed elevation angle, and thus forms a cone of coverage in space) of Chilbolton radar. Reflectivity and radial wind are saved as a function of range, azimuth, and elevation. Some further process is required before assimilation, via averaging of raw data to grid size of the model.

2 Main Challenges:

- Quantitative precipitation forecasts.
- Accurate estimate forecasts.
- Data assimilation at high resolution.
- Loss of vertical resolution of the data.

- Microphysics parameters.
- Sensitivity.
- The nonlinearly and uncertainty of the observation operators.

3 Observational Needs:

- Radar radial velocity and reflectivity data (surface observations).
- High-intensity rain-gauge.
- Suitable filtering technique.

4 Data Preprocessing and Quality Control (for 4D-Var approach):

Doppler radar data have a range-gate spacing of 200–300 m for radial velocity and about 1 km for reflectivity, and an azimuth spacing of 1 degree for both variables radial velocity and reflectivity. The number of elevations (between 9 to 14 elevations) depends on the storm mode. The resolution in vertical direction depends on the range and becoming rather poor at large distance from the radar. Then the vertical resolution of model grid is much better than the vertical resolution of the radar data. However, the horizontal resolution of the radar data is much better than that of the model grid. Most of quality control is performed on 1-km: the original radar data are interpolated to about 1-km Cartesian grid in the horizontal before they are used. After quality control, further interpolation are made to the data (to match model grid) to be 3-5 km grid in the horizontal while remaining on the constant elevation angles levels on the vertical.

Further quality control can be made to remove the contaminated data by nearby ground clutter as well as clutter resulting from anomalous propagation, by the way that any velocity data with values less than 0.25 m/s and corresponding reflectivity are removed (see Sun & Crook (1998)). A final quality check is to remove any remaining spurious data by computing the standard deviation of each data point from its local mean.

The reflectivity return from hydrometeors is not conserved, these data should me be removed or a source term added to the reflectivity equation. For simplicity, you may only consider the effect of precipitation fallout. You may use a threshold value of 12 dBZ to distinguish reflectivity return from clear air and from hydrometeors; that is any reflectivity data greater than 12 dBZ are regarded as returns from hydrometeors.

3D-Var is used with Doppler radar data grided at 5 km and run the model with 10-km resolution. Assimilation of reflectivity, using 3D-Var is not promising

5 Advantage of Direct Assimilation of PPI data:

Due to the poor vertical resolution of radar data, a vertical interpolation from radar data from constant elevation levels to model Cartesian levels can result in large errors. For this reason a direct assimilation of PPI data with no vertical interpolation is recommended. On each constant elevation level, data are interpolated from 2D polar grid to 2D Cartesian grid. This is due the fact that radar data have better horizontal resolution than that of the model resolutions (the poorest polar radar data is approximately 2-km at the farthest range distance in the analysis domain is better than the resolution of the model grid). This may be an optimal interpolation within the context of the 4D-Var formulation. An observation operator $\mathcal{H}$ must me formulated to map the model variables from model grid such that the distance between the observations and model solution is estimated in the cost function.

Since the vertical resolution of the model is much better than that those of radar data, we use this relation In this case the observation operation $\mathcal{F}$ is formulated to map the data from the model vertical levels to the elevation angle levels via the formula

$$v_{r,e} = \mathcal{F}(v_r) = \frac{\sum e^{-z/2\beta^2} v_r \Delta z}{\sum e^{-z/2\beta^2} \Delta z}, \tag{1}$$

where $v_{r,e}$ is the radial velocity on an elevation angle level and Δz is the model vertical grid spacing. β^2 is the beam half-width and z is the distance from the center of radar beam. The summation is over the model grid points that lie in a radar beam.

6 Observing System Simulation Experiment (OSSE):

In this study we test 3D-Var and 4D-Var approaches using simulated data form from a specific day. Such a simulation experiment is referred to as OSSE. The forecast model is a 3D cloud model, and the prognostic variables include three velocity components u, v, w, potential temperature θ , pressure p , and categories of water substances (such as water vapor specific humidity q_v , cloud water mixing ratio q_c , rainwater mixing ratio q_r, cloud ice mixing ratio q_i , snow mixing ration q_s , and hail mixing ration q_h).

For all experiments unless otherwise notes, the physical domain is $64km \times 64km \times 16km$. The model grid comprises of grid points, with grid interval 2-km in both x and y directions and 0.5 km in the vertical.

7 Simulation of Radar Data:

The simulated data are assumed to be available on the grid points. The radial velocity is calculated from

$$v_r = u \cos\alpha \sin\theta + v \cos\alpha \cos\theta + w \sin\alpha \tag{2}$$

where α is the elevation angle and θ is the azimuth angle of radar beam.

The logistic reflectivity is estimated from the log formula

$$dBZ = 10 \log(Z), \quad \text{with} \quad Z = Z_r + Z_s + Z_h, \tag{3}$$

where Z_r, Z_s, Z_h are contribution from rain, snow and hail, respectively.

8 Project Steps:

- Pre-processing Doppler data before assimilation: re-scale the radar data at a spatial resolution that corresponds with that used in the NWP model, using super-obbing technique.
- Setting up an OSSE (Observing System Simulation Experiment)
- Formulating the Observation Operator for radial velocity and reflectivity and their adjoints and insert them into the Unified Model.
- Running Met Office 3D-Var system for Doppler radial velocity, having a time window of 3 hours at 5-km grided data resolution and 10-km model resolution.
- Running 4D-Var system for 1-km data resolution and 1-5 km model resolution.
- Investigating the impact of assimilating reflectivity combined with radial velocity.