Doppler Radar Data Assimilation with WRF 3D-Var: IHOP Retrospective Studies

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1. Introduction

It has been recognized that assimilation of multiple Doppler radar observations is one of the critical aspects for improving 0-12 hr forecasts of precipitation and other high-impact weather. The case study of the IHOP_2002 squall line on 13 June 2002 using WRF 3D-Var, demonstrated that radar data assimilation improved the cold pool initialization and hence the QPF skill (Xiao and Sun 2007). Recently, we made progresses for the IHOP retrospective studies using WRF 3D-Var Doppler radar data assimilation. Firstly, we processed conventional and Doppler radar observations in the IHOP domain from 10 June through 15 June 2002. The Doppler radar data from 25 radar stations went quality control using the Variational Doppler Radar Analysis System (VDRAS, Sun and Crook 1997; 1998; Crook and Sun 2004). Secondly, we conducted background error statistics using the real time WRF forecasts from 14 April to 15 May 2007, and interpolated it to the IHOP domain for WRF 3D-Var. Thirdly, numerical experiments were designed for the IHOP retrospective studies. Some preliminary results from case studies using WRF 3D-Var Doppler radar data assimilation will be presented in the 9th WRF user's workshop. We will also discuss our future plan to further evaluate the capability of WRF 3D-Var Doppler radar data assimilation with the IHOP retrospective experiments.

2. Radar Data Processing

We used VDRAS to process the radar data. Firstly, the input data was processed to 1km x 1km resolution at elevation angles. We eliminated ground-clutter contamination when the radial velocity $v_r < 0.1$ ms^{-1}. We also removed noise of the v_r and reflectivity data that have high local variance. If the local variance of v_r (reflectivity) in the 3 x 3 grid points is greater than 60 m^{2}s^{-2} (150 dbZ^2), we treat the data as noise and remove it. The threshold value is determined empirically. In addition, we filter out the isolated and questionable velocities. If there are more than 3 of its 8 neighboring in 3 x 3 grid points are missing, it is assigned a missing value. Secondly, we conducted de-aliasing for the v_r data. There are 3 steps in the de-aliasing: a) a baseline run is used to provide a reference wind to de-alias v_r; b) the local average wind is used to de-alias v_r; c) velocity at each elevation angle is manually edited as a final checkup. Thirdly, we filled some missing data. If there are data at more than 20 grid points in at least 2 quadrates in a 9 x 9 grid box, the missing data is filled using the average in the box. The final output data was interpolated to the same resolution as model runs (3 km) by bi-linear interpolation scheme at each elevation angle. It contains the data with 3D-Var format of radial velocity, reflectivity and their errors. The errors in the datasets are the standard deviation calculated from the data at 3 x 3 grid points. We assigned the Min/Max radial velocity error of 1.0/10.0 ms^{-1}. From 0000 UTC 10 till 1200 UTC 15 June 2002, 6 days of Doppler radar data for the 25 radar stations in the US Great Plain were processed with 3 hour interval. We found that only 113 volumes of data need manual editing for

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de-aliasing. Most of the aliased v_r data were automatically corrected with the baseline reference wind or local average wind. Figure 1 shows the v_r data from the radar sites KDDC and KLNX at 0900 UTC 11 June 2002 before and after de-aliasing. It is demonstrated the de-aliasing procedure works well.

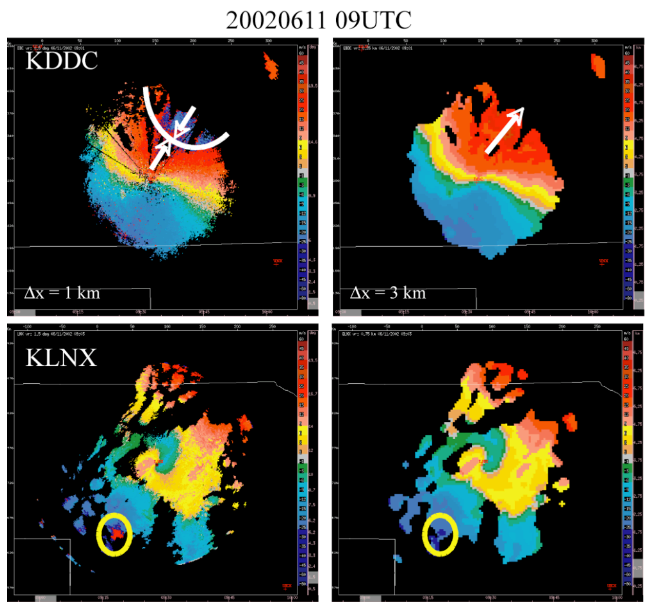

Fig. 1: Radial velocity V_r from the radar stations KDDC (top) and KLNX (bottom) at 0900 UTC 11 June 2002 before (left) and after (right) de-aliasing

3. Experiment Design

The experimental domain covers an 1800 x 1800 km^2 centered in the Great Plain area. The advanced research WRF (ARW) model (Skamarock et al. 2005) is used for all experiments. The model physics include the YSU planetary boundary layer parameterization (Hong et al. 2006), and Thompson microphysics scheme (Thompson et al. 2004). The model resolution is 3km, and there is no cumulus scheme used in all WRF forecasts.

We used the newly updated WRF-Var 3.0, which has revised Doppler radar data assimilation capability in our study (Skamarock et al. 2005). The WRF 3D-Var was developed from its previous version for MM5 application (Barker et al. 2004). Within the WRF 3D-Var, we developed the capability of radial velocity assimilation (Xiao et al. 2005) and reflectivity assimilation (Xiao et al. 2007). The WRF 3D-Var radar data assimilation has been run in operational application in Korea since 2005 (Xiao et al. 2008). However, its usage in US is still limited to case studies. In this retrospective study, we plan to access its capability for an extended period of time from 0000 UTC 10 to 1200 UTC 15 June 2002 using the IHOP_2002 campaign data.

The first-guess of cold-start runs is interpolated from NCEP/NAM analysis using the WRF preprocessing system (WPS). We used the archived forecasts in 15 April - 14 May 2007 to calculate the background error statistics with NMC method (Parrish and Derber 1992). Observations include conventional data, plus all

Doppler radar data from 25 sites. In order to examine the impact of radar data assimilation, we conducted the following experiments: CNTL (control run, with the initial conditions from NCEP/NAM interpolated analysis with WPS); GTS (the experiment with the enhanced analysis assimilating only conventional data); GTSRD (the experiment with the enhanced analysis assimilating both the conventional data and radar data from 25 sites); and GTSRD3 (the experiment with the continuous analysis/forecast cycling of conventional and radar data every three hours). In the cycling experiment, WRF 3D-Var analysis is updated at 00h, 03h 06h, … , at every 3 hour (Fig. 2). The WRF model runs 36 hours at 0000 and 24 hours at 1200 UTC every day. The lateral boundary conditions for all experiments are from WPS analysis with BC update.

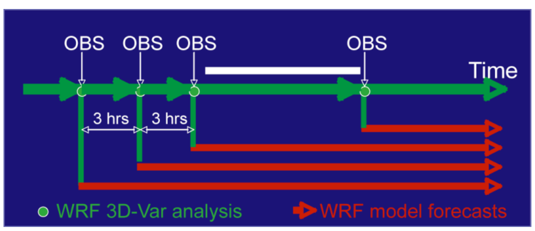

Fig. 2: Schematic diagram of the WRF 3D-Var analysis/WRF forecasting cycling experiment

4. Results

The preliminary results present an encouraging impact of radar data assimilation on the convective systems. Until now, we have finished CNTL, GTS and GTSRD experiments. The WRF 3D-Var assimilation/WRF model forecast cycling experiment, GTSRD3, has not finished yet. Among the cold-start experiments (CTNL, GTS and GTSRD), Doppler radar data assimilation (GTSRD experiment) shows improved rain-band pattern compared with GTS and CNTL. Here, we will just show the results from 0000 UTC 12 June 2002. Figure 3 presents the observed radar reflectivity at 0400 UTC 12 June (Fig. 3a), and the 4-hr forecasts of reflectivity from CNTL, GTS and GTSRD at the same time (Figs. 3b-d). Comparing with CNTL, the experiment GTS did not get noticeable improvements. The convective system in observation shows a long line (Fig. 3a), but both the CNTL and GTS have a short-lined convection (Figs. 3b and c). After assimilating the radar data at the initial time (GTSRD), however, the experiment recovers a similar pattern as the observed. At 0600 UTC, the convective system developed and the lined-convection moved to the Kansas/Oklahoma border (Fig. 4a), but both CNTL and GTS forecasted the convection system in the mid of Kansas far from the border. On the other hand, the experiment GTSRD adjusted the convective system and predicted a similar position and pattern as observed.

Usually, the positive impact of radar data assimilation cannot be expected beyond 6 hours. However, the forecast from 0000 UTC 12 June seems to continue the improvement after 6 hour. Figure 5 shows the results at 1200 UTC 12 June 2002, 12 hours after the model initial time. The observed radar reflectivity (Fig. 5a) becomes a south-north pattern in the southeast of Kansas. The experiment GTSRD (Fig.5d) produced the best simulation, which has a similar pattern as observed, but with a little larger scale. The worst simulation was seen in CNTL (Fig. 5b); it absolutely over-predicts the convective system, both in intensity and scale. The forecast from experiment of GTS (Fig. 5c) adjusted some from CNTL, but still produced a wrong pattern comparing with the observed. The results show a promising behavior of Doppler radar data assimilation in this case. We will further analyze the results and conduct more experiments to assess its capability in the near future.

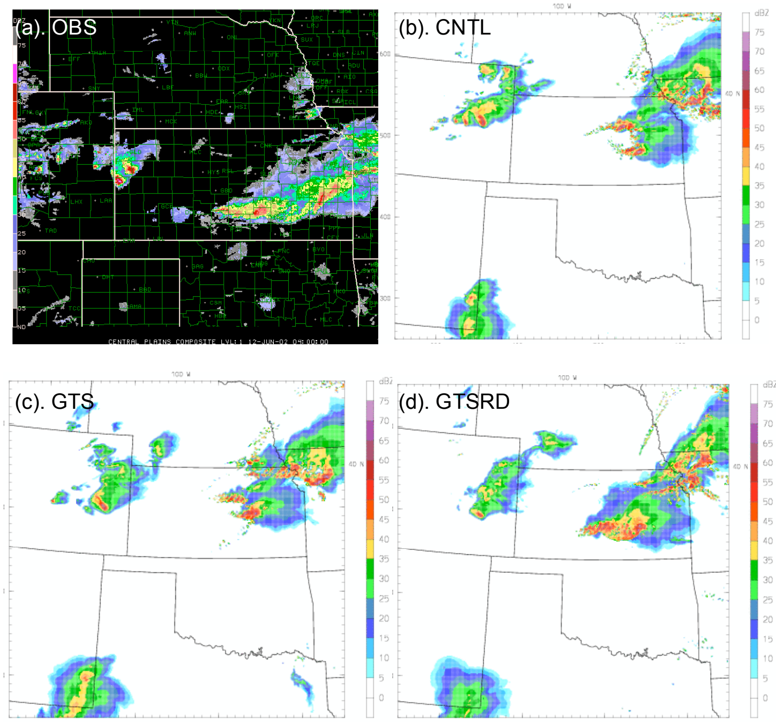

Fig. 3: The pattern of reflectivity at 0400 UTC 12 June 2002:

(a) observed, (b) CNTL, (c) GTS, and (d) GTSRD

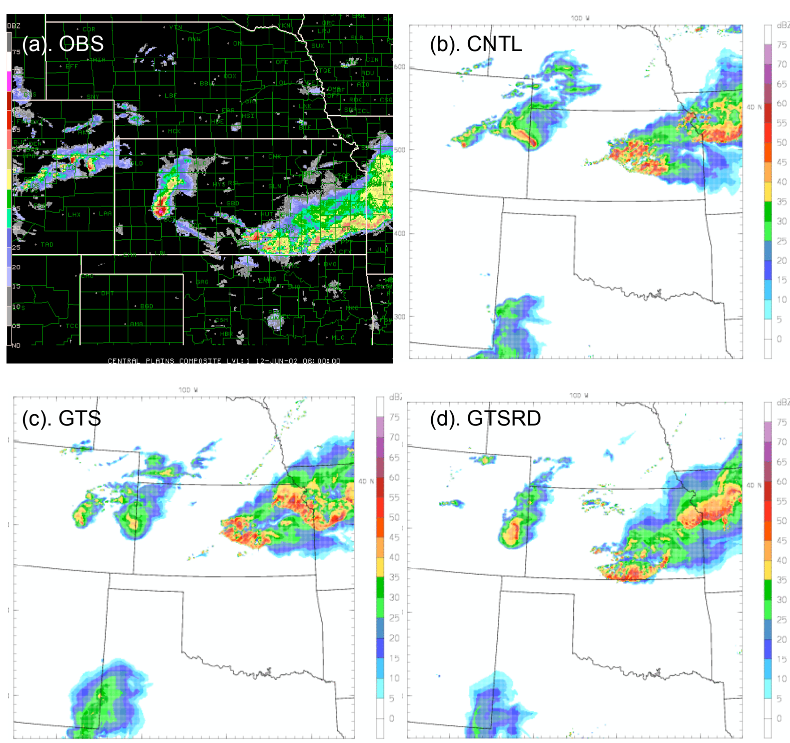

Fig. 4: The same as Fig. 3, but at 0600 UTC 12 June 2002

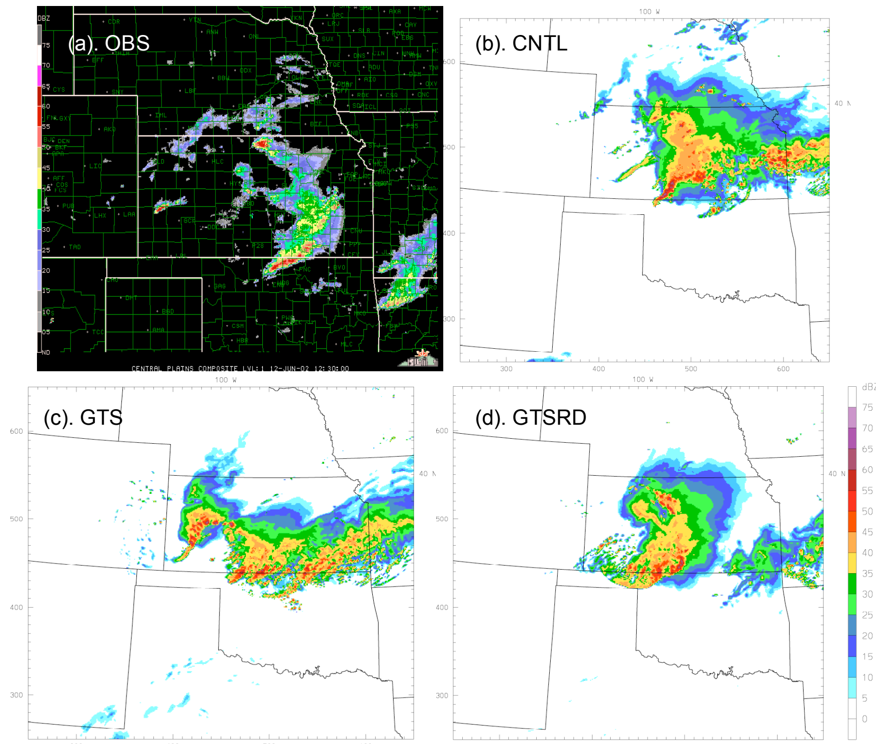

Fig. 5: The same as Fig. 3, but at 1200 UTC 12 June 2002

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