# ASSIMILATION OF DUAL-POLARIMETRIC RADAR OBSERVATIONS AND THEIR IMPACT ON FORECAST OF CONVECTIVE WEATHER

Xuanli Li and John Mecikalski
University of Alabama in Huntsville, Huntsville, AL

ABSTRACT

Dual-polarimetric (dual-pol) Doppler radars transmit and receive both horizontally and vertically polarized radio wave pulses. Using the enhanced measurement, dual-pol variables can provide more information about the liquid and solid cloud and precipitation particles, hence obtain more accurate estimate of rainfall and hydrometeors than non-polarimetric weather radars. The assimilation of dual-pol radar data is a challenging work. At present, not much effort has been given into the dual-pol radar data assimilation research field. With the ongoing upgrade of the current U.S. NEXRAD radar network to include dual-polarimetric capabilities, the dual-pol radar network will cover the whole country within the next couple years. The time is upon us to begin exploring how to best use the polarimetric data to improve forecast of severe storm and forecast initialization.

Our presentation will highlight our recent work on assimilating the dual-pol radar data for real case convective storms. In our study, high-resolution WRF model and its 3DVAR data assimilation system are used to assimilate the dual-polarimetric radar data collected by the C-band Advanced Radar for Meteorological and Operational Research (ARMOR) radar (located at Huntsville International Airport (34.6804°N, 86.7743ºW)). In this study, horizontal reflectivity ($Z_H$), differential reflectivity ($Z_{DR}$), specific differential phase ($K_{DP}$), and radial velocity (VR) collected by the C-band Advanced Radar for Meteorological and Operational Research (ARMOR) were assimilated for a convective storm. Details of the methodology of data assimilation, the influences of different dual-pol variables on model initial condition and on the short-term prediction of precipitation, and the results for the real case storms, will be presented.

## 1. INTRODUCTION

Despite steady improvement in the high-resolution numerical weather prediction (NWP) models, it is still a challenge to predict accurately the evolution of convective storms and related quantitative precipitation forecast (QPF). Studies have shown that radar data assimilation can help with short-term prediction of convective weather by providing more accurate initial condition (Sun 2005).

The dual-polarimetric (dual-pol) radar typically transmits both horizontally and vertically polarized radio wave pulses. From the two different reflected power returns, information on the type, shape, size, and orientation of cloud and precipitation microphysical particles are obtained, more accurate measurement of liquid and solid cloud and precipitation particles can be provided (Seliga and Bringi 1976). With the upgrade of the current NWS WSR-88D radar network to include dual-pol capabilities started in last year, the dual-pol radar network will cover the whole continental U.S. in the next couple years. It is our goal to examine how to best use the dual-pol radar data to improve forecast of severe storm and forecast initialization.

The assimilation of dual-pol radar data has not been explored much in past researches. Jung et al. (2008) represents lately studies that successfully assimilated dual-pol radar data into the observing system simulation experiments (OSSEs). In this paper, we explore the methodology and evaluate the impact of data assimilation of the dual-pol variables using real case events.

## 2. MODEL AND DATA ASSIMILATION PROCEDURE

Doppler radar observations used in this study were collected by the Advanced Radar for Meteorological and Operational Research (ARMOR). ARMOR is a C-band Doppler radar located at Huntsville International Airport (34.6804°N, 86.7743ºW) which was upgraded to include dual-pol capabilities in October 2006. The ARMOR radar transmits/receives in both single polarization and simultaneous horizontal/vertical polarization modes (*Petersen et al.* 2007). More information about data process can be found in Li and Mecikalski (2010). An isolated summer time thunderstorm (meso-β scale) in the afternoon of 23 June 2008 was selected for this study. This storm initiated near 1500 UTC on June 23 over eastern Tennessee with a size of only ~10 km in diameter. After about 3–4 hours, the system intensified and grew into a meso-β scale storm.

This study uses the Weather Research and Forecasting model (Skamarock et al. 2008) and the three dimensional variational data assimilation method. A WRF control run (CTRL) is conducted. Two set of data assimilation experiments are conducted to examine the impact of the dual-pol variables. The following radar forward operators are constructed:

$$Z_H = 2.04 \times 10^4 \times q_r^{1.75} \qquad (1)$$

is based on Sun and Crook (1997). It is used in “RF” to assimilate only $Z_H$ and VR data.

$$q_r = 0.6 \times 10^{-3} \times Z_H^{0.85} \times \Im_{DR}^{-2.36} \qquad (2)$$

(Bringi and Chandrasekar 2001) is used in “RD” to assimilate $Z_H$, $Z_{DR}$ and VR data. Another set of experiments compares the influence of $Z_{DR}$, and $K_{DP}$ data assimilation.

$$q_r = 2.32 \times K_{DP}^{0.83} \times \Im_{DR}^{-1.11} \qquad (3)$$

is based on Bringi and Chandrasekar (2001),

and $q_r = 3.11 \times K_{DP}^{0.918} \times Z_{DR}^{-0.764}$ (4)

is based on Ryzhkov and Zrnić (1995). “KD” assimilates $K_{DP}$, $Z_{DR}$ and VR data with forward operator (3). “KD2” use operator (4) for data assimilation.

## 3. RESULT

Figure 1 shows reflectivity at the end of the data assimilation cycle from the NEXRAD radar image, model CTRL run, and experiments of RF and RD. The WRF model control run only produces scattered convective clouds, but at locations far from the one observed. In contrast, after the assimilation of ARMOR variables, the structure of the storm has been largely improved. Specifically, with cycled assimilation of ARMOR $Z_H$ and VR data, RF produces strong convection over northern Alabama/southern Tennessee. After assimilating $Z_H$ and $Z_{DR}$ data, the main feature of the strong convective region over northern/central Alabama is retrieved in RD. The location is very close to the observed one, even though the size of the storm is still smaller than the observed echo.

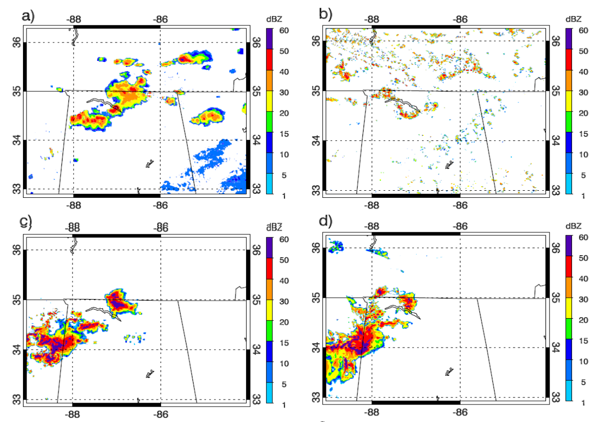

**Figure 1.** Radar reflectivity at 2 km altitude around 2030 UTC 23 June 2008 from a) NEXRAD radar image, b) the WRF model control run, c) analysis from RD, d) the analysis from RF.

Figure 2 plots the horizontally averaged absolute values of **O** – **B** and **O** – **A** in the first cycle of data assimilation at 1930 UTC 23 June 2008. In model control run, the maximum of averaged absolute value of **O** – **B** is 11.1 dBZ. The large value of averaged **O** – **B** occurs between surface and 6 km altitude. After the assimilation of the ARMOR data, the difference between the observation and data assimilation analysis is substantially reduced. The maximum averaged **O – A** decreases greatly to

4.3 in RF and 3.7 dBZ in RD. In KD, the averaged **O** – **A** values are generally smaller than the values in RD and RF at most levels. Below 6 km altitude, the averaged **O** – **A** values in KD are about 0.5 dBZ less than those in RD and roughly 1 dBZ less than RF.

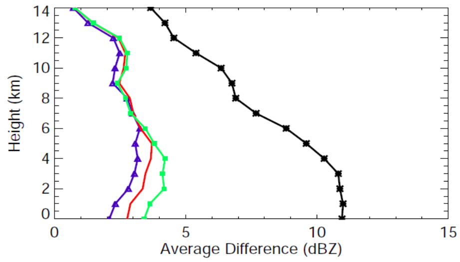


**Figure 2.** Vertical distribution of the horizontally averaged absolute values of (O – B) from model control run (black) and (O – A) from experiments RF (green), RD (red) and KD (purple) at 1930 UTC 23 June 2008.

Figure 3 shows the calculated forecast *Threat Scores* for each experiment from 2030 to 2230 UTC with threshold values of 10, 20, 30, and 40 dBZ. NXRD1730 generally has a very low score at all four threshold values. In contrast, *TS*s for RF, RD and KD are much higher. For example, *TS*s for NXRD1730 are not more than 0.06 at the threshold of 10 dBZ, while *TS*s can be as high as 0.34, 0.46 and 0.55 for RF, RD and KD, respectively. This apparently indicates the significant positive impact of ARMOR radar data assimilation. In addition, KD generally produces larger *TS* values than RD and RF most of the times, which verifies the beneficial effect of assimilating the $K_{DP}$ and $Z_{DR}$ data into the initial condition.

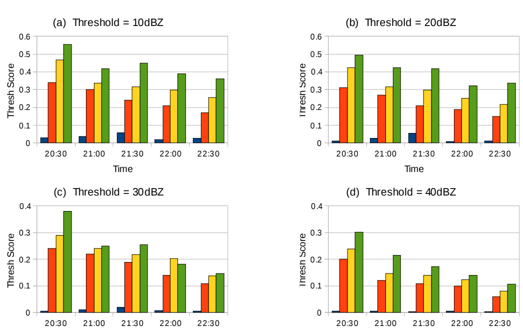


**Figure 3.** Threat scores of horizontal reflectivity for control (blue), RF (orange), RD (yellow), and KD (green) for a) threshold = 10 dBZ, b) threshold = 20 dBZ, c) threshold = 30 dBZ, and d) threshold = 40 dBZ from 2030 to 2230 UTC 23 June 2008.

The use of different operators does produce large influence on the structure of the storm. Figure 4 displays the difference in reflectivity distribution at the end of the data assimilation cycle (2030 UTC 23 June 2008) from KD and KD2. The location of the storm in KD2 is pretty close to the one in KD, meaning that the use of different observational operator didn't cause big difference in storm initialization in terms of location and general pattern. On the other hand, the detailed distribution of hydrometeors has large difference between KD and KD2. The convective core (>40 dBZ) in KD is slightly weaker, reflected by the negative values in the storm region over northern Alabama. It is shown that, the reflectivity difference between KD and KD2 is mostly within [-5, 5] dBZ. Only sporadic points of large values in reflectivity difference are found at strong echo region.

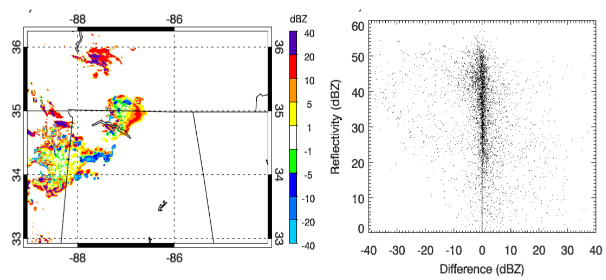


**Figure 4.** Radar reflectivity at 1 km altitude around 2030 UTC 23 June 2008 for the difference between KD2 and KD, and scatter plot of reflectivity in KD2 vs. reflectivity difference from KD–KD2.

The difference in initial condition between KD and KD2 causes significant different pattern in short-term forecast in term of the detailed microphysical property. Figure 5 compares reflectivity at 1 km height from NEXRAD radar image and forecast from KD and KD2. Both KD and KD2 capture the weakening trend of this thunderstorm at this time. The pattern and location in both data assimilation experiments are in good agreement with the observed storm at 2200 UTC, implying that the difference in the assimilation analysis at initial time did not cause big difference in the short-term prediction in terms of storm movement and evolution. However, when compared with the observed reflectivity, KD captures better the structure of the storm in the eastern part over Alabama/Georgia, while KD2 has a broader coverage with a better structure over the western part in central Alabama. The biggest difference in KD and KD2 is the distribution in strong echo region, which indicates that the forecast of micorphysical processes and hydrometeor distribution are largely influenced by the difference in the initial condition.

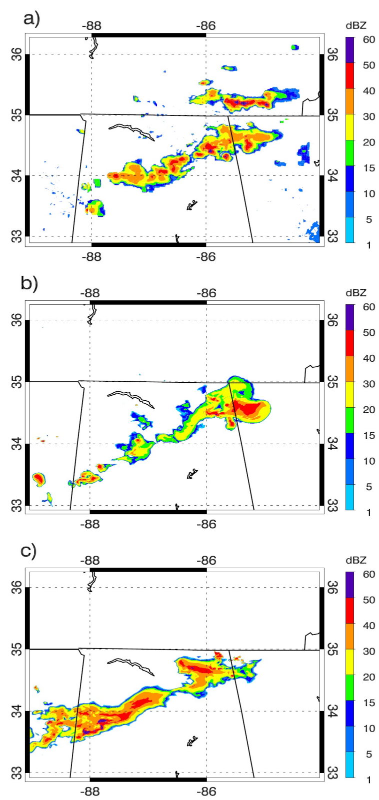


**Figure 5.** Horizontal reflectivity at 1 km altitude from a) NEXRAD radar image, b) forecast for KD2, c) forecast for KD at 2200 UTC 23 June 2008.

SUMMARY

The result indicates that the benefit from assimilation of several dual-pol radar variables in storm initialization and short-term forecast. However, dual-pol radar data assimilation research is still at its very early stage. Our current ongoing research focuses on building the ice-phased microphysical processes in the WRF 3DVAR package. With the successes of dual-pol radar data assimilation for warmrain processes in this study, we are increasingly curious, when the more sophisticated ice-phased microphysical forward model is developed for dual-pol observations, how much more improvement can be obtained for numerical modeling of convective storms.

REFERENCE

Bringi, V. N., T. Keenan, V. Chandrasekar, 2001: Correcting C-band radar reflectivity and differential reflectivity data for rain attenuation: A self-consistent method with constraints, *IEEE Trans. Geosci. Remote Sens.,* **39**, 1906–1915.

Li, X., and J. R. Mecikalski, 2010: Assimilation of dual-polarimetric Doppler radar data for a convective storm with a warm-rain radar forward operator, *J. Geophys. Res.,* **115**, D16208, doi:10.1029/2009JD013666.

Jung, Y., M. Xue, G. Zhang, and J. M. Straka, 2008a: Assimilation of simulated polarimetric radar data for a convective storm using the Ensemble Kalman Filter. Part II: Impact of polarimetric data on storm analysis, *Mon. Wea. Rev.,* **136**, 2246–2260.

Petersen, W. A., K. R. Knupp, D. J. Cecil, and J. R. Mecikalsi, 2007: The Unversity of Alabama Huntsville THOR Center instrumentation: Research and operational collaboration, paper presented at 33rd International Conference on Radar Meteorology, 6–10 August, 2007, Cairns, Australia.

Ryzhkov, A., and D. Zrnić, 1995: Comparison of dual-polarization radar estimators of rain, *J. Atmos. Oceanic Technol.,* **12**, 249–256.

Seliga, T.A., and V.N. Bringi, 1976: Potential use of radar differential reflectivity measurements at orthogonal polarizations for measuring precipitation, *J. Appl. Meteor.,* **15**, 69–76.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, M. G. Duda, X.-Y. Huang, W. Wang, and J. G. Powers, 2008: A description of the advanced research WRF version 3. NCAR Technical Note, NCAR/TN-

475+STR, NCAR, Boulder, CO.
Sun, J., and N. A. Crook, 1997: Dynamical and microphysical retrieval from Doppler radar observations using a cloud model and its adjoint. Part I: Model development and simulated data experiments. *J. Atmos. Sci., 54,* 1642-1661.
Sun, J., 2005: Initialization and numerical forecasting of a supercell storm observed during STEPS, *Mon. Wea. Rev.* **133**, 793–813.

Acknowledgments
This work was supported by NSF grants AGS-1005354.