Extended Abstract, 25th Conference on Severe Local Storms
Amer. Meteorol. Soc., Denver, CO, Oct. 2010

Three-dimensional Analyses of Several Thunderstorm Cases Observed by Hunan's Regional Radar Network

Chenghao Fu[1], Chengzi Ye[1], Zuxian Li[1], Lin Xu[1], Jidong Gao[2], and Ming Xue[2]
[1]Human Meteorological Observatory, Hunan, P. R. China
[2]Center for Analysis and Prediction of Storms, University of Oklahoma, USA

1. Introduction

With the use of the Next Generation Radar (88D, or 98D in China) Doppler network, meteorologists can provide better information to the public, ultimately saving lives and property, by remotely observing the internal structure of thunderstorms at high resolution. However, the assimilation of such data into NWP models has not been extensively explored. At the convective scales, Doppler radar is the only operational instrument capable of providing observations of high enough spatial and temporal resolutions. Therefore, effective assimilation of Doppler radar data into operational convection-resolving models is of increasing importance as nonhydrostatic models are being adopted at several meteorological centers and the full-volume data from the entire radar network will become available in China very soon.

Several methods exist for the assimilation of radar data. Sun et al. (1991) and Sun and Crook (1997, 1998) have shown that four-dimensional variation analysis (4DVAR) is an idealized approach to assimilate radar data. However, to assimilate radar data, 4DVAR has so far been limited to relatively simple model configurations, usually with warm-rain microphysics only (Sun 2005). Computational cost and strong nonlinearity with model physics, including ice microphysics, often causes difficulties in 4DVAR assimilation of radar data. Ensemble Kalman filter (EnKF) is another advanced method for assimilating radar data (Snyder and Zhang 2003; Zhang et al, 2004; Dowell et al. 2004; Tong and Xue 2005; Gao and Xue 2008). Caya et al. (2005) showed that EnKF and 4DVAR produce analyses of generally similar quality and computational cost. Though these two methods are advanced methods theoretically, they are rather expensive computationally, especially at the convection-resolving resolution. For realtime analysis and forecasting for convective weather, the three-dimensional (3DVAR) data assimilation method is a computationally efficient method comparing to 4DVAR and EnKF (Gao et al. 1999, Xiao et al. 2005). A 3DVAR system, ARPS 3DVAR system, is developed for ARPS model (Xue et al. 2000, 2001). As described in Gao et al. (2004; 2005), the ARPS 3DVAR system is capable of analyzing radar radial velocity data along with conventional observations in a very efficient way. To compensate the lack of a time dimension in 3DVAR method, experiments are usually performed using rapid intermittent analysis cycles to make better use of data distributed in time (Hu et al. 2006). The ARPS 3DVAR system is usually supplemented by a cloud analysis package which analyzes hydrometer variables using radar reflectivity and satellite observations (Brewster 2003a, b). Several studies (e.g ., Hu et al. 2006; Ge et al. 2009; Schenkman et al. 2009) have shown reasonable success in simulating and forecasting convective storms including tornadoes and supercells using the ARPS 3DVAR data assimilation system. In this study, we report a preliminary data assimilation case by using the ARPS 3DVAR and its cloud analysis system to Hunan province's regional two Doppler radars. The numerical forecasts using the data assimilation result as initial conditions will be our future focus. Data from two S-band radars were collected in real-time during the summer of 2010. Using radial wind and reflectivity data from these radars, several Mesoscale Convective Systems (MCS) were selected and data assimilation experiments were performed using the 3DVAR method. These several cases were run in University of Oklahoma's super computer during the first author's visit there. These cases demonstrated a potentially benefit of use Doppler weather radars to provide the forecasters severe weather situation awareness capability. Our major effort for the next several years will be to provide reliable, real-time 3DVAR analysis product to forecasters for improving severe weather detection and prediction using data from radar data. Section 2 provides a brief description of a MCS event and its analysis. A summary and future work is discussed in Section 3.

2. Case Description and Result

A local heavy rain and severe convective weather event occurred from 18:00 on to 00:00 (UTC) on May 5th, 2010 in central south of Hunan province in China (Fig.1). It was triggered by an eastward moving trough from Bay of Bengal, and the appearance of southwest low with strong wind shear along the east of Yangtze and Huaihe river, which led surface cold air moving down from the east of the Riverband area (Fig. 2).

Corresponding author new address: Mr. Chenghao Fu, Hunan Meteorological Observatory, Changsha, Hunan, PRC, 410007. Chenghaofu@hotmail.com.

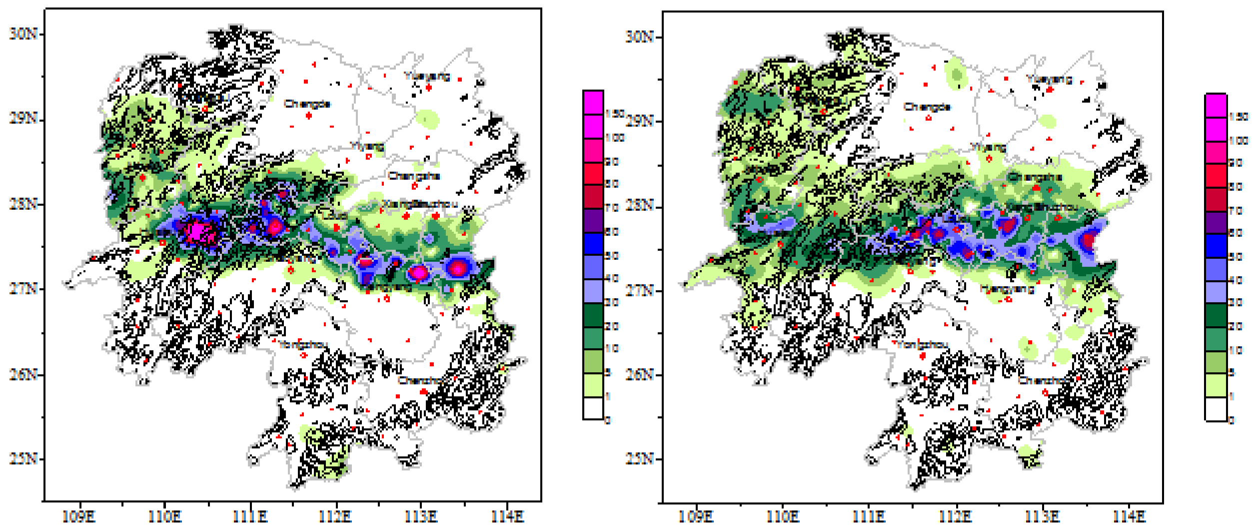

Fig. 1. (left panel) Precipitation observed by the surface rain gauge from 18 UTC to 21 UTC (a), and from 21 UTC, May 5 to 00 UTC, May 6, 2010 (b).

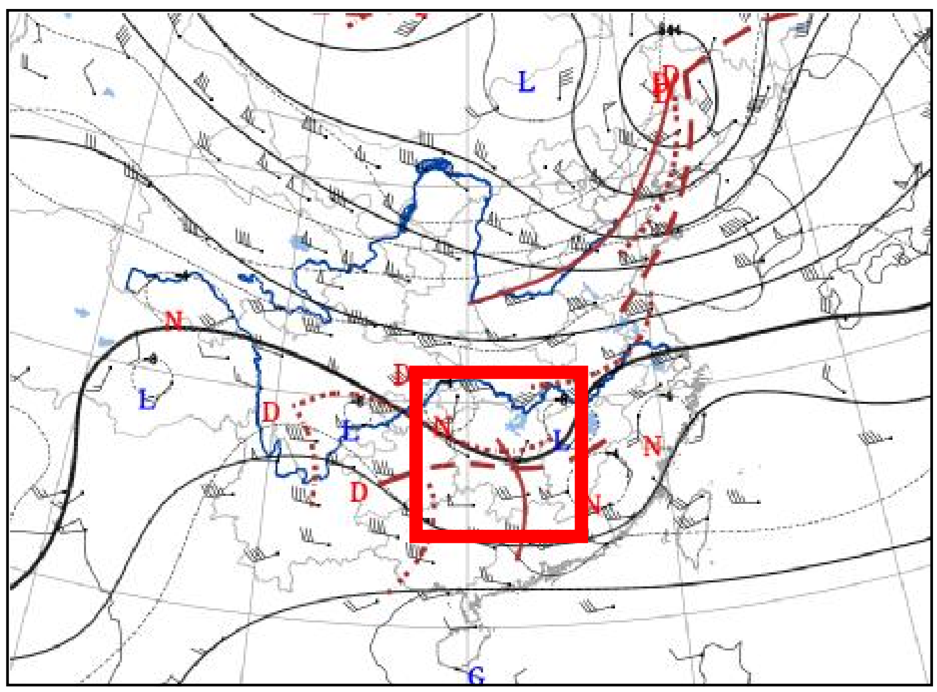

Fig. 2. Environmental conditions at 0000 UTC 6 May 2010 shown by 500 hPa geopotential height (black real-line contours), temperature(black dashed-line contours),and wind barb. (brown real-line is 500hPa trough line; brown dotted-line is 700hPa trough line;brown dashed-line is 850hPa trough line)

Maximum daily rainfall was 246.4 mm; maximum hourly rainfall was 93mm (Fig. 1). This event was very strong, happened very quickly, and produced heavy short-term rainfall. The spatial distribution of heavy rain event was along a narrow strip. It caused a severe mountain hazard for most central south area of Hunan province.

ARPS 3DVAR analysis system allows for the combination of radar data with all available data sources, including sounding data and surface data. The analysis products can be used by the forecasters for short severe weather events and may help them issue severe weather warnings. The system has been used to perform low level wind analysis by the Center for Adaptive Sensing of Atmosphere (CASA) for realtime display of severe weather events since 2008 and some forecasters who used this product repeatedly pointed out that gridded wind analysis was much more intuitive to use (Gao et al. 2009).

For the current study, the ARPS 3DVAR was run on a 400x400 km grid at 1 km grid spacing. In the vertical, the analysis grid is stretching with 25 physical model layers, representing a physical extension to 15 km AGL. Multiple processors on the University of

Oklahoma OSCER supercomputer were used. The wind analyses were performed every 5 minutes and they

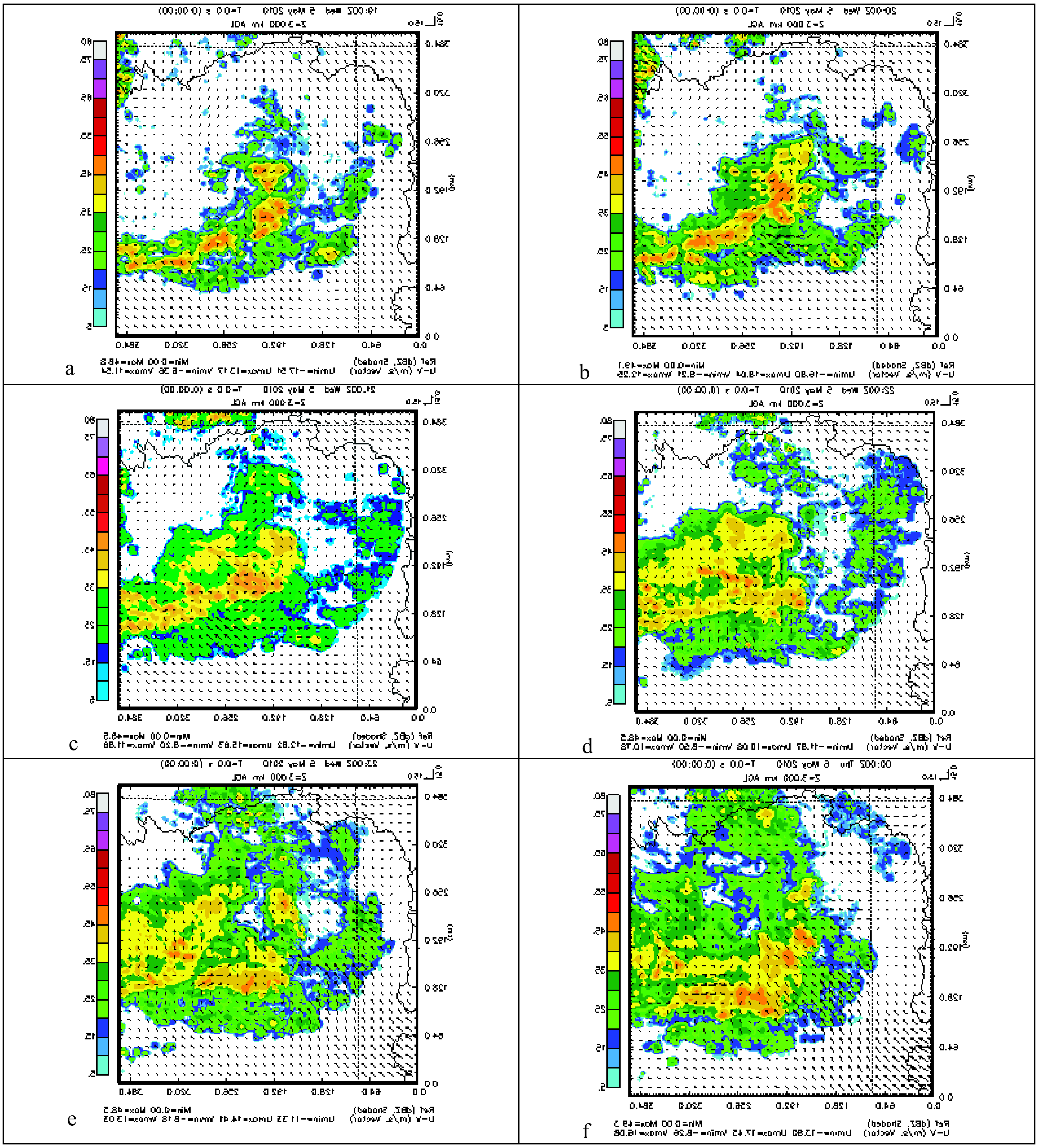

Figure 3. The total u-v wind vector, and reflectivity (colored) at z=3 km AGL for a local heavy rain and severe convective weather event occurred at central south of Hunan province of China, (a) at 1900 UTC, (b) at 2000 UTC, (c) at 2100 UTC, (d) at 2200 UTC, (e) at 2300 UTC on 5 May 2010 , (f) 0000 UTC on 6 May 6, 2010.

included the radial velocity and reflectivity data from two 88D typed radars (Changsha and Changde). Other data used include dense surface data, traditional sounding data and airport reports from Hunan Regional Meteorological Observatory, together with the operational GFS model analysis/forecast background from US NCEP. Compared to conventional dual-Doppler wind synthesis method, a variational system is able to produce a useful analysis, using all data available, even in regions where radial velocity data are not available. The high spatial and temporal resolutions of the radar data provide an unprecedented opportunity for documenting detailed severe weather structures for real-time warning and prediction applications.

Figure 3 shows the 6-hour evolution of middle level (at 3 km AGL) wind vectors and reflectivity field during the time period of MCS which produced above described heavy rain event. At 1900 UTC (*Fig. 3a*), a weak convergence area was observed near central Hunan province along west-north and east-south direction and this alerted the forecasters that a possible strong MCS could develop. One hour later, at 2000 UTC, the convergence became stronger and a narrow circulation also developed near the center of the analysis domain (*Fig. 3b*). With the time going on, the precipitation spread to nearby area but the strength became a little bit weaker, and the heavy precipitation remained at some area lasted for several hours caused big troubles for some counties of the province (*Fig. 3c-3f*). The precipitation became weaker after 0000 UTC, 6 May. The forecasters noted this event by looking at radar images, but did not expect the precipitation was so strong and produced heavy damage to people's properties.

3. Summary and future work

We have successful implemented ARPS-3DVAR to Hunan Province which is usually dominated by severe weather events during the summer time. Preliminary tests indicate that the analysis can represent the flow structures of this storm very well and provide a unified composite reflectivity field from two Doppler radars. Though only one MCS case is reported here, the results look very reasonable. Based on the ARPS 3DVAR system, the analysis was able to take advantage of dual or multiple Doppler velocity coverage of the radars. Compared to raw radial velocity data, these analyses may be easier to use and interpret by forecasters, and are spatially and temporally much more continuous. Chinese storms (though only one case is presented here because of time constraint) usually produce heavy rain, similar to Mesoscale Convection System (MCS) frequently observed within US, but not well-organized as US MCSs. The circulations within these severe storms are generally weaker than US severe storms.

We will test the capability and effectiveness of ARPS-3DVAR system for different types of weathers in south China by more experiments. Our major effort in the next few years will be to provide a reliable and robust real-time 3DVAR analysis product to the forecasters of local meteorological agencies of Hunan province for improving the severe weather detection and nowcasting using data from all 8 mixed C-band and S-band radars together with other data sources including traditional soundings and surface data. We have a plan to do NWP model forecasts with ARPS and/or WRF model which will be initialized using ARPS-3DVAR system.

Acknowledgments. The work was supported by National Natural Science Foundation of China, No. 41075034. The OSCER/University of Oklahoma was acknowledged for providing computational facility.

REFERENCES

Brewster, K. A., 2003a: Phase-correcting data assimilation and application to storm-scale numerical weather prediction. Part I: Method description and simulation testing. *Mon. Wea. Rev.*, **131**, 480-492.

Brewster, K. A., 2003b: Phase-correcting data assimilation and application to storm scale numerical weather prediction. Part II: Application to a Severe Storm Outbreak. *Mon. Wea. Rev.,* **131**, 493-507.

Caya, A., J. Sun, and C. Snyder, 2005: A comparison between the 4D-VAR and the ensemble Kalman filter techniques for radar data assimilation. *Mon. Wea. Rev.*, **133**, 3081–3094.

Dowell, D.C., F. Zhang, L.J. Wicker, C. Snyder, and N.A. Crook, 2004: Wind and Temperature Retrievals in the 17 May 1981 Arcadia, Oklahoma, Supercell: Ensemble Kalman Filter Experiments. *Mon. Wea. Rev.*, **132**, 1982–2005.

Gao, J., M. Xue, A. Shapiro, and K. K. Droegemeier, 1999: A variational method for the analysis of three-dimensional wind fields from two Doppl radars. *Mon. Wea. Rev.,* 127, 2128-2142.

Gao, J., M. Xue, K. Brewster, and K. K. Droegemeier 2004: A three-dimensional variational data assimilation method with recursive filter for single-Doppler radar, *J. Atmos. Oceanic. Technol.* **21**, 457-469.

Gao, J., C. Nuttall, C. Gilreath, M. Xue, K. Brewster, and K. Droegemeier, 2005: Multiple Doppler wind analysis and assimilation via 3DVAR using simulated observations of the planned CASA network and WSR-88D radars, 11th conf. on mesoscale processes and 32nd Conference on Radar Meteorology, CDROM J1J.4.

Gao, J., J. A. Brotzge, Y. Wang, K. W. Thomas, K. Brewster, M. Xue, V. Chandrasekar, Y. Wang, B. D. Phillips, and M. Zink, 2009: High Temporal and Spatial Resolution 2D Wind Analysis of CASA and WSR-88D Radar Data using the ARPS 3DVAR. Preprint, 13th Conf. IOAS-AOLS, Phoenix, AZ., Amer. Meteor. Soc., Paper 6.4.

Ge, G., and J. Gao, 2007: Latest development of 3DVAR system for ARPS and its application to a tornadic supercell storm, 22nd Conference on Weather Analysis and Forecasting/18th Conference on Numerical Weather Prediction, on-line publication, 2B.6.

Hu, M., M. Xue, J. Gao, and K. Brewster, 2006: 3DVAR and cloud analysis with WSR-88D level-II data for the prediction of Fort Worth tornadic thunderstorms. Part II: Impact of radial velocity analysis via 3DVAR. *Mon. Wea. Rev.*, **134**, 699–721.

Tong, M. and M. Xue, 2005: Ensemble Kalman filter assimilation of Doppler radar data with a compressible nonhydrostatic model: OSS Experiments. *Mon. Wea. Rev.*, **133**, 1789-1807.

Schenkman, A., M. Xue, A. Shapiro, K. Brewster, and **J. Gao**, 2010: Impact of radar data assimilation on the analysis and prediction of the 8-9 May 2007 Oklahoma tornadic mesoscale convective system - Mesoscale features on a 2 km grid. *Mon. Wea. Rev.* (accepted).

Sun, J., D. W. Flicker, and D. K. Lilly, 1991: Recovery of three-dimensional wind and temperature fields from simulated single-Doppler radar data. *J. Atmos. Sci.*, **48**, 876-890.

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., and N. A. Crook, 1998: Dynamical and microphysical retrieval from Doppler radar observations using a cloud model and its adjoint. Part II: Retrieval experiments of an observed Florida convective storm. *J. Atmos. Sci.*, **55**, 835–852.

Sun, J., 2005: Initialization and numerical forecasting of a supercell storm observed during STEPS. *Mon. Wea. Rev.*, **133**, 793-813.

Xiao, Q., Y. Kuo, J. Sun, W. Lee, E. Lim, Y. Guo, and D. M. Barker, 2005: Assimilation of Doppler Radar Observations with a Regional 3DVAR System: Impact of Doppler Velocities on Forecasts of a Heavy Rainfall Case. *Journal of Applied Meteorology and Climatology*, **44**, 768-788.

Xue, M., K. K. Droegemeier, and V. Wong, 2000: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. *Meteor. Atmos. Physics*, **75**, 161-193.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D. Wang, 2001: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. *Meteor. Atmos. Phy.*, **76**, 143-165.

Zhang, F., C. Snyder, and J. Sun, 2004: Impacts of initial estimate and observations on the convective-scale data assimilation with an ensemble Kalman filter. *Mon. Wea. Rev.*, **132**, 1238-1253.