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

Chenghao Fu¹, Chengzi Ye¹, Zuxian Li¹, Lin Xu¹, Jidong Gao², and Ming Xue²
¹Human Meteorological Observatory, Hunan, P. R. China
²Center 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; Schenckman et al. 2009) have shown reasonable success in simulating and forecasting convective storms including tornades 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 Huaie 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 500hPa trough line; brown dotted-line 700hPa trough line; brown dashed-line is 850hPa trough line)

Maximum daily rainfall was 246.4 mm; maximum hourly rainfall was 93 mm (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](image)

*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.

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