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ENKF ANALYSIS OF THE 29 MAY 2004 OKLAHOMA CITY SUPERCELL USING RAPID-SCAN PHASED ARRAY RADAR DATA

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I. INTRODUCTION

The Phased Array Radar (PAR) is a new and unique Doppler radar (10 cm) that rapidly scans precipitating clouds via electronic beam steering. It is a part of the National Weather Radar Testbed (NWRT) in Norman, Oklahoma. The PAR is the first phased array radar system adapted to observe weather. On 29 May 2004 the PAR observed a tornadic supercell as it traversed central Oklahoma causing considerable damage beginning near the town of Geary, OK and continuing eastward through northern sections of the Oklahoma City metropolitan area. This data set represents the first tornadic supercell observed using a rapid-scan 10-cm radar, covering a 90 degree sector using seven elevation angles every 20-30 seconds during a three-hour period when the storm was within 150 km of the radar. Rapid-scan radar data is believed to be a critical tool needed to produce real-time high-resolution storm-scale analyses and forecasts for the explicit prediction of severe weather such as hail and tornadoes. Accordingly, this study investigates whether the use of rapid-scan data positively impacts storm-scale analyses and forecasts relative to less-frequent radar data volumes now available from the U.S. Weather Surveillance Radars, 1988, Doppler (WSR-88D) radar system. Storm-scale EnKF techniques developed by Dowell and Wicker (2009, hereafter known as DW09) are used to assimilate the PAR Doppler and reflectivity data from the 29 May 2004 tornadic storm, producing storm-scale analyses and forecasts that are compared to those produced by using less frequent data.

II. EXPERIMENT DESIGN

The PAR data were collected over a 90° sector, with seven elevation angles, 0.75°, 2.27°, 3.78°, 5.28°, 6.78°, 8.28°, and 9.78°. As soon as a volume scan was completed a new scan started, making the times of the scans irregular but approximately every 20 seconds. This study uses data from 0050 UTC to 0140 UTC because the tornadic storm was located within 100 km from the radar beginning at 0050 UTC. The gate spacing for the radar beam is 0.24 km. The PAR beamwidth is a function of the azimuthal angle from the flat-plated radar dish. At the center of the sector scan, the beam width is 1.5°, which then broadens to 2.1° at both edges sector. The raw PAR data required hand editing to remove velocity and range aliasing as well as ground clutter near the radar. The radar data are then objectively analyzed to a horizontal 2 km Cartesian grid on the individual PPI scan using a Cressman scheme. This analysis technique is used to thin the data horizontally to decorrelate observation errors while not introducing error via vertical interpolations.

The cloud-scale model used in the data assimilation system is the NSSL Collaborative Model for Multiscale Atmospheric Simulation (NCOMMAS). The Lin-Farley-Orville (LFO) microphysics scheme is used. The model domain is 120 km in the horizontal and 20 km in the vertical. The model grid moves to match storm motion, which was 6 m s^{-1} to the east during the integration period. The grid spacing is 2 km in the horizontal and 400 m in the vertical. Forty ensemble members are used. The 2236 UTC Weatherford, OK sounding is used to initialize the ensemble members at 0030 UTC. Variations among the ensemble members are created by randomly adding warm 5.0 K bubbles in the localized area where the observed storm reflectivity is greater then 15 dBZ during the next twenty minutes as in DW09. Each member is integrated for 20 minutes before PAR data is assimilated. The ensemble spread is maintained using additive noise following DW09. The additive noise is applied every time a radar volume is assimilated and the perturbation values were chosen to provide sufficient ensemble spread. Objectively analyzed PAR radial velocity and reflectivity as well as no precipitation observations are assimilated into the model beginning at 0050 UTC. The reflectivity observations are not used to update potential temperature or water vapor mixing ratio, as several studies have found this helps mitigate excessive model error growth in the boundary layer.

One experiment assimilates a single PAR volume every five minutes that is similar to the data frequency of the operational WSR-88D network currently running in the United States. This experiment is therefore designated as *"five-minute simultaneous",* hereafter denoted as 5min. A data assimilation experiment to assess the potential impact of rapid-scan data uses a three-dimensional PAR volume every minute. This experiment is called *one-minute simultaneous* (or rapid-scan), hereafter denoted as 1min.

III. RESULTS AND CONCLUSIONS

The results show that assimilating the one-minute data decreases the spin-up time (the time required for the analysis to develop deep convection and capture the basic storm structure) compared to the conventional five-minute data. Results are evaluated by examining the analysis fields for the characteristic structures of tornadic supercells. For example, after ten minutes of data assimilation (not shown), the 1min analysis has a well-developed storm having supercell reflectivity structures, including a hook echo, strong precipitation core, forward flank, and mesocyclonic circulation in the wind field. However, the 5min experiment shows a poorly organized and still-developing storm. Reduction of spin-up time is important toward being able to initialize storm-scale forecasts quickly and accurately.

After twenty minutes of data assimilation the 1min z = 1 km reflectivity (Fig. 1) analyses depict a distinct hook echo and heavy precipitation core. The 5min reflectivity analyses only depict a developing inflow notch. The hook echo is believed to strongly reflect the presence of a deep mesocyclonic circulation, which is confirmed by examining the flow and vertical velocity. The analyzed wind field indicates a strong mesocyclone with nearly a closed circulation, while the 5min analysis wind field only has weak cyclonic flow around the updraft. The 1min experiment's vertical velocity analysis has a stronger updraft near the cloud base of approximately 14 m s^{-1} and what could be a rear-flank downdraft (RFD). The 5min analysis has a weaker updraft near the cloud base (~8 m s^{-1}) and a less intense downdraft that is outside the mesocyclone region of the storm. In the inflow region of the 1min analyses at 0111 UTC (Fig. 1) there is a maximum in positive vertical vorticity nearly collocated with the maximum in vertical velocity. The 5min analysis has weaker updrafts and smaller values of vertical vorticity generally collocated in the inflow region. The motion and vorticity are weaker and more spatial diffuse compared to the 1min analyses. Therefore the 1min experiment has developed a more vigorous supercell compared to the 5min assimilation experiment. West to east vertical cross-sections slicing through the updraft of each 1min and 5min storm (Fig. 1) also show significant differences in supercell structure and intensity. A Bounded Weak Echo Region (BWER) is present in the both cases. However, the 5min BWER is shallower with the largest reflectivity considerably downshear of the main storm updraft. This suggests a less mature storm. The 1min experiment has a strong updraft (maximum vertical velocity ~39 m s^{-1}) collocated with the BWER location. Vertical vorticity values in the 1min experiment are indicative of a significant mesocyclone.

Near the surface (the lowest model layer which is located at 0.2 km AGL, not shown) the 1min potential temperature analyses depict a more mature cold pool structure at this time. The 5min experiment's cold pool is weaker and more disorganized. The 1min analysis has cold air under the forward flank and a region of warm air that could be descending air from the RFD on the upshear region of the storm. As the data assimilation continues, however, the temperature deficits within the cold pool grow too large. These deficits are believed to be much smaller in most tornadic supercells. Our experiments suggest the intensity of the cold air results from the accumulation of model error associated with the microphysical parameterization. The dynamics associated with an overly strong cold pool subsequently affect the whole storm system, and lead to a premature "gusting out" and demise of the analyzed supercell storm.

Verifying convective storm analyses is difficult due to a lack of direct observations from within the convective system. The 29 May 2004 storm is unique in that a number of operational and research radars were able to observe the storm. However, using other radars to compare model results presents challenges due to the differences between the various radar systems and difficulties involved with pre-processing the data. Preliminary statistics indicate that the 1min experiment radial velocities inside the storm have lower root-mean-square innovations than the 5min experiment. Further results from these comparisons will be shown at the conference.

To summarize, the EnSRF experiment using the one-minute PAR volumes generates a vigorous supercell that appears to be most similar to the observed storm. The 1min storm analyses contains typical supercell features after only 10-15 minutes of assimilation, while in the 5min experiment these features are broader, weaker, and less mature. Rapid-scan radar data therefore "spins-up" the supercell storm much more quickly in a storm-scale EnKF analysis system relative to analyses generated via the current operational data frequency. Rapid-scan data also helps reduce the analysis errors relative to those seen in the conventional data assimilation, even after the conventional analyses have "caught up" and contain a mature convective storm.

IV. AKNOWLEDGMENTS

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V. REFERENCES

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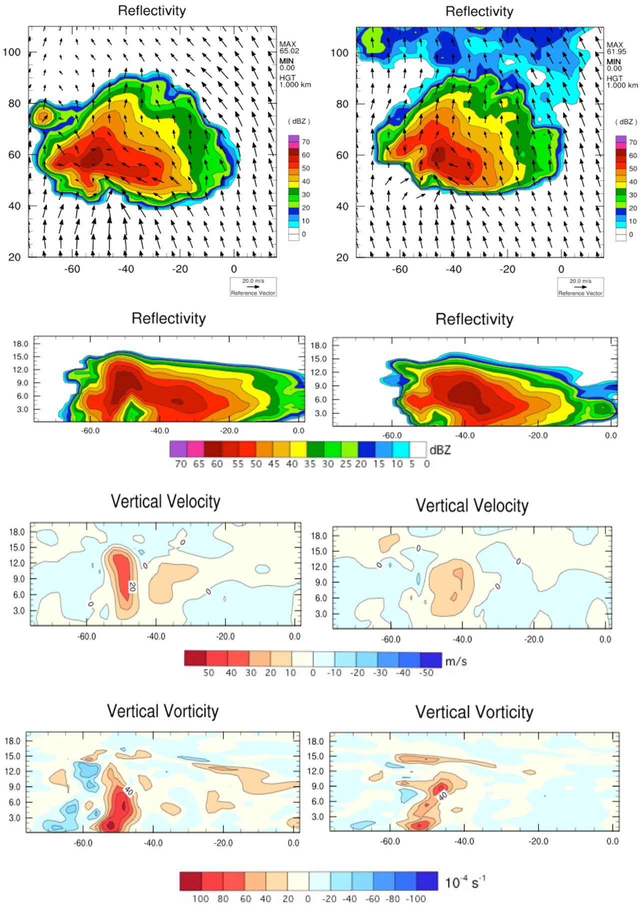

FIG. 1: 0111 UTC EnSRF analyses of vertical cross-sections of reflectivity, vertical velocity, and the vertical vorticity for the (left) 1min assimilation experiment and (right) 5min assimilation experiment.