Multiple Doppler Analysis for 20 May 2013 Tornadic Supercell using a 3DVAR

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1. Introduction

The proper early identification of a supercell thunderstorm, or a supercell embedded in a cluster of storms, is critical to the issuance of public warnings for severe weather. One of the defining characteristics of a supercell is the existence of a mid-level mesocyclone (Lemon and Doswell, 1979). The mesocyclone was originally defined as the Doppler radar velocity signature of a storm-scale vortex (Burgess, 1976), which corresponds to the rotating updraft–downdraft couplet of a supercell thunderstorm. Mesocyclones in the United States are typically cyclonic and also may contain a more intense tornadic vortex. However, most of these early studies were performed using only observations from one radar, or two radars.

With the overlap of multiple WSR-88D Doppler radar coverage in some places, we can do Doppler radar analyses with the help of NWP model products. This type of multi-radar approach has already proven useful for improved quantitative precipitation estimation (QPE) using radar reflectivity observations, as demonstrated by both the National Mosaic and Multi-Sensor QPE (NMQ) system (Zhang et al. 2011) and the Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan et al. 2007). This kind of high-resolution analysis that includes observations from multiple sources can help overcome several limitations. First, using multiple observations of the same feature improves the analyses as errors decrease with aggregation. Second, the use of multiple radars can help fill in data voids, such as those below the lowest and above the highest radar-scanning angle. Third, while forecasters make their warning decisions based on the best information available, the escalating data flow rates from new sensors and applications, combined with the workload and timeliness requirements, may limit forecasters' ability to effectively use all available information. This situation can be ameliorated by fast data assimilation methods that merge all available information together as quickly as possible for human decision makers.

In this study, we investigate behaviors of the mesocyclones embedded in the May 20, 2014 Moore, Oklahoma tornadic supercell by merging all available information together using the ARPS 3DVAR data assimilation system (Gao et al. 2004; Gao et al. 2013). The system can produce physically consistent high-resolution analyses based on multiple data sources including observations from several nearby WSR-88Ds and operational model forecasts. The rest of this paper is organized as follows. Section 2 provides an overview of May 20 2013 tornado case and the 3DVAR data assimilation (DA) system. Some preliminary results are reported and assessed in section 3. We conclude in section 4 with a summary and outlook for future work.

2. The description of 20 May 2013 Moore Tornadic Storm and experiment settings

An EF5 tornado struck Moore, OK and adjacent areas on the afternoon of May 20, 2013, resulting in 23 fatalities and 377 injuries. Peak winds and maximum width were estimated at 210 mph (340 km/h) and 1.3 miles, respectively. According to *Storm Data*, the tornado touched down west of Newcastle at 1956 UTC (2:56 pm local time). The tornado lifted around 2035 UTC with a 17 mile path length. This event was observed very well by KTLX radars. Several nearby radars including KFDR, KINX and KVNX also observed part of this storm. Assisted by the NCEP NAM NWP product, which was used as a background state, the detailed structure of the mesocyclone which produced the May 20, 2014 Moore tornado will be analyzed. Our analysis will focus on the period during tornado touchdown.

A real-time, weather-adaptive 3DVAR system (based on ARPS 3DVAR) has been developed recently for the Warn-on-Forecast project (WoF) to incorporate all available WSR-88D radar observations within an analysis domain that could be hit by severe weather, including tornadoes, hails and strong damaging winds (Gao et al. 2013). The unique features include: (1) The ability to automatically detect and analyze severe local hazardous weather events at 1km horizontal resolution every 5 minutes. (2) The analysis can also be performed with on-demand capability in which end-users (or forecasters) set up the location of the analysis domain in real time based on the current weather situation. (3) The analysis product can help forecasters identify strong circulations embedded in thunderstorms so that the accuracy of warnings for hazardous weather threats may be improved. Although still in the early development stage, the system performed very well during the spring of the last several years (Clark et al. 2013; Gao et al. 2013; Smith et al. 2014; Calhoun et al. 2014). Many severe weather events were successfully detected and analyzed. The system was used by the NWS forecasters as one of the official projects of the NOAA's HWT Experimental Warning Program in 2011 and 2012.

Similar to the realtime settings, the domain selected for May 20, 2014 Moore tornado case has 200 x 200 horizontal grid points with a 1 km grid spacing. In the vertical direction, 31 terrain-following vertical layers are used, with nonlinear stretching via a hyperbolic tangent function, thus yielding an average vertical grid spacing of 400 m. During that day, the two-dimensional (2D) composite reflectivity product covering the 48 contiguous United States from the WDSS-II real-time system (Lakshmanan et al. 2007) at the National Severe Storm Laboratory (NSSL) was used to identify the four locations (longitude, latitude) at risk for severe storms. This composite reflectivity product helped automatically choose the analysis domain with the center of (-97.18° W, 35.36° N) that covers the May 20 Moore tornado case. The latest available NCEP operational NAM (Janjic et al. 2003) analysis and forecasts were obtained and interpolated to the 3DVAR domains using linear interpolation in time and quadratic interpolation in space, and four WSR-88D radars are automatically selected for the analysis. The complete 3DVAR real-time system procedure is shown schematically in Fig. 1 and was performed every 5 min. Our focus is on the 3D wind analyses and wind-derived variables, such as vertical velocity and vertical vorticity.

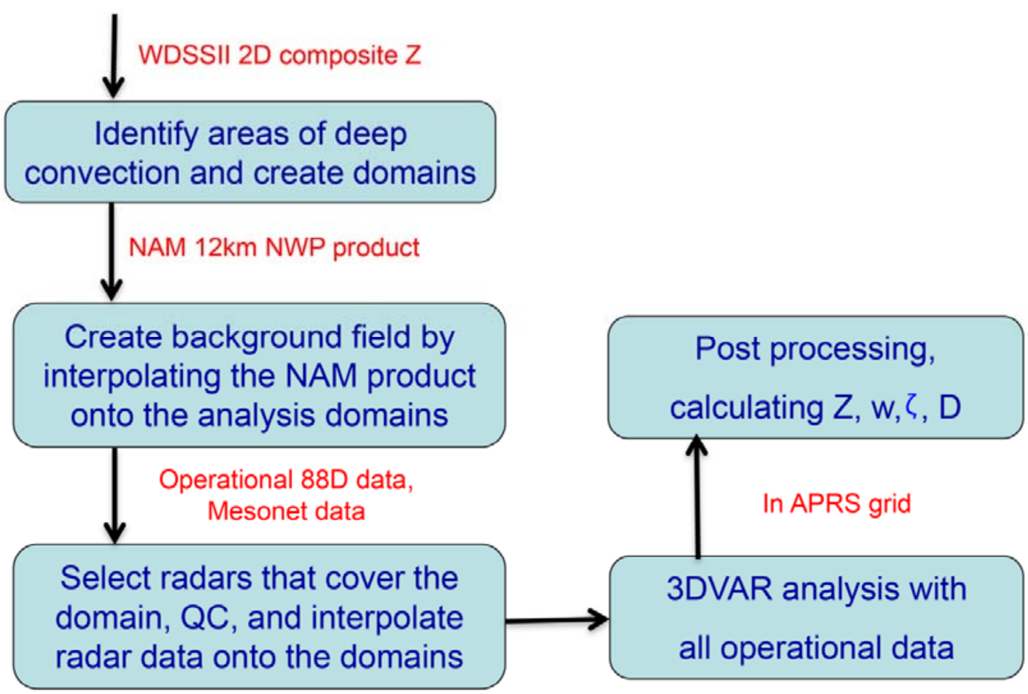

Fig. 1. The flow chart of the weather-adaptive 3DVAR System.

3. Results

On May 20, 2013, a central upper trough moved eastward with a lead upper low over the Dakotas and upper Midwest region. A southern stream shortwave trough moved east-northeastward over the southern Rockies to the south, with severe thunderstorms forming during the peak hours of heating. The air mass was expected to become unstable across much of the southern Great Plains and the most intense severe weather activity was expected across the southern Great Plains, specifically Central Oklahoma, during the afternoon hours. During that day the Storm Prediction Center issued a moderate risk of severe thunderstorms during the early morning hours of May 20 from southeastern Missouri to north-central Texas. The supercell that produced the Moore tornado developed very quickly. The storm initiated around 1900 UTC (2:00 pm local time), quickly intensified, and the tornado first touched down west of Newcastle at 1956 UTC (Fig. 2).

During the 2013 spring season, we did not formally test our program in the NOAA Hazardous Weather Testbed, but the program was run occasionally when there were possible severe weather events. We started our run around 1800 UTC on May 20. The system automatically relocated the analysis domain near Moore, Oklahoma. The analyzed horizontal winds, vertical vorticity at 3 km above ground, and interpolated radar reflectivity depicted the storm from the beginning to its peak intensity from 1900 UTC to 2035 UTC 20 May (Fig. 2 and Fig. 3). Around 1900 UTC, there was a weak storm cell near the western boundary of the analysis domain (Fig. 2a, Fig. 3a). But the storm that produced the Moore tornado quick intensified. After only 25 minutes (1925 UTC), this cell evolved into a supercell (Fig. 2b, Fig. 3b). The wind analysis at low-middle level (3km AGL) indicates a very strong mid-level cyclonic circulation.

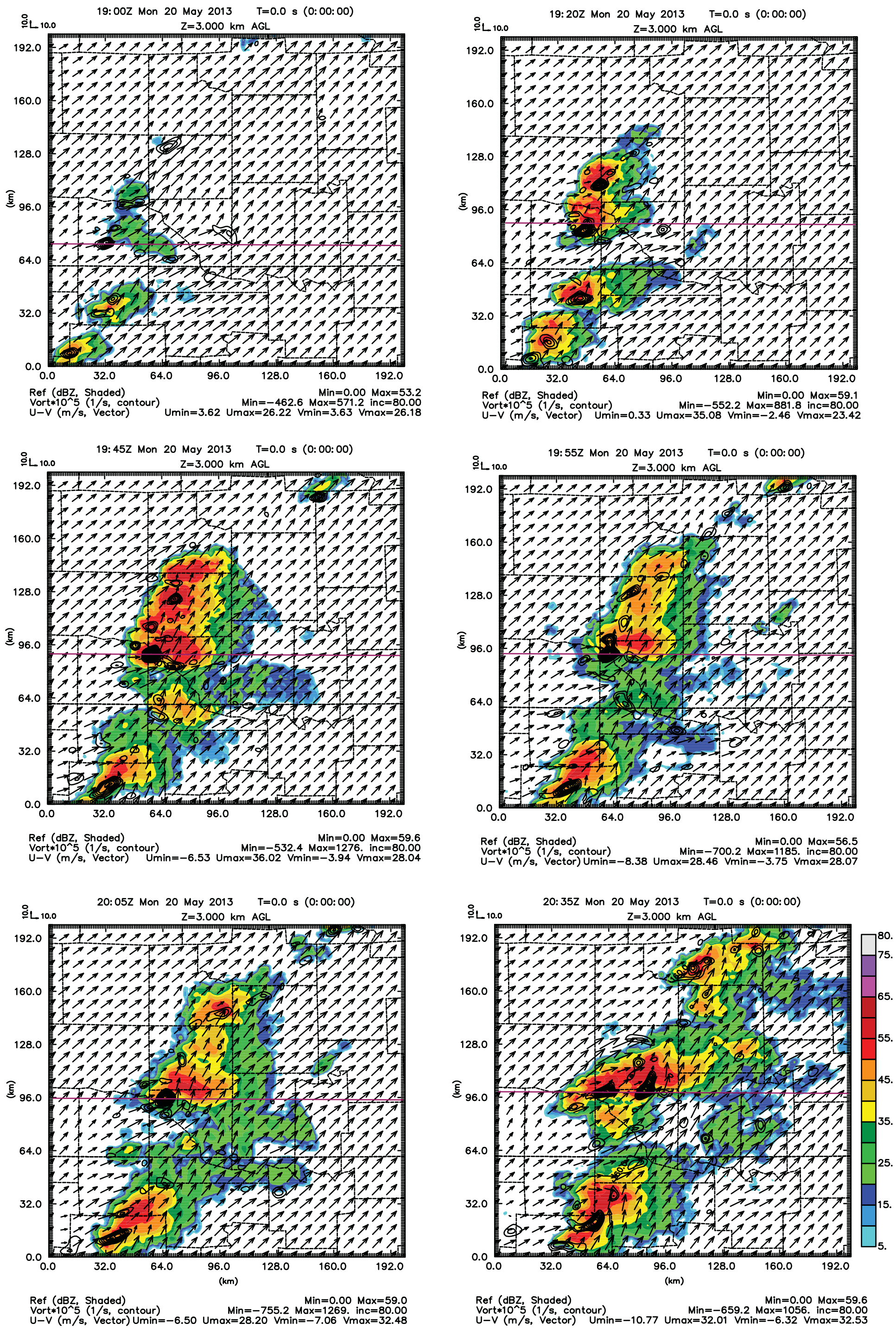

Fig. 2. The synthesized reflectivity (color shaded), and analyzed horizontal wind fields (vectors), and vertical vorticity (black contours) at 3 km AGL at (a) 1900 UTC, (b) 1920 UTC, (c) 1945 UTC, (d) 0050 UTC, (e) 0055 UTC, and (f) 0100 UTC, 20 May 2013 near Moore, Oklahoma. Maroon line denotes location of cross-sections for vertical slices in Fig. 3.

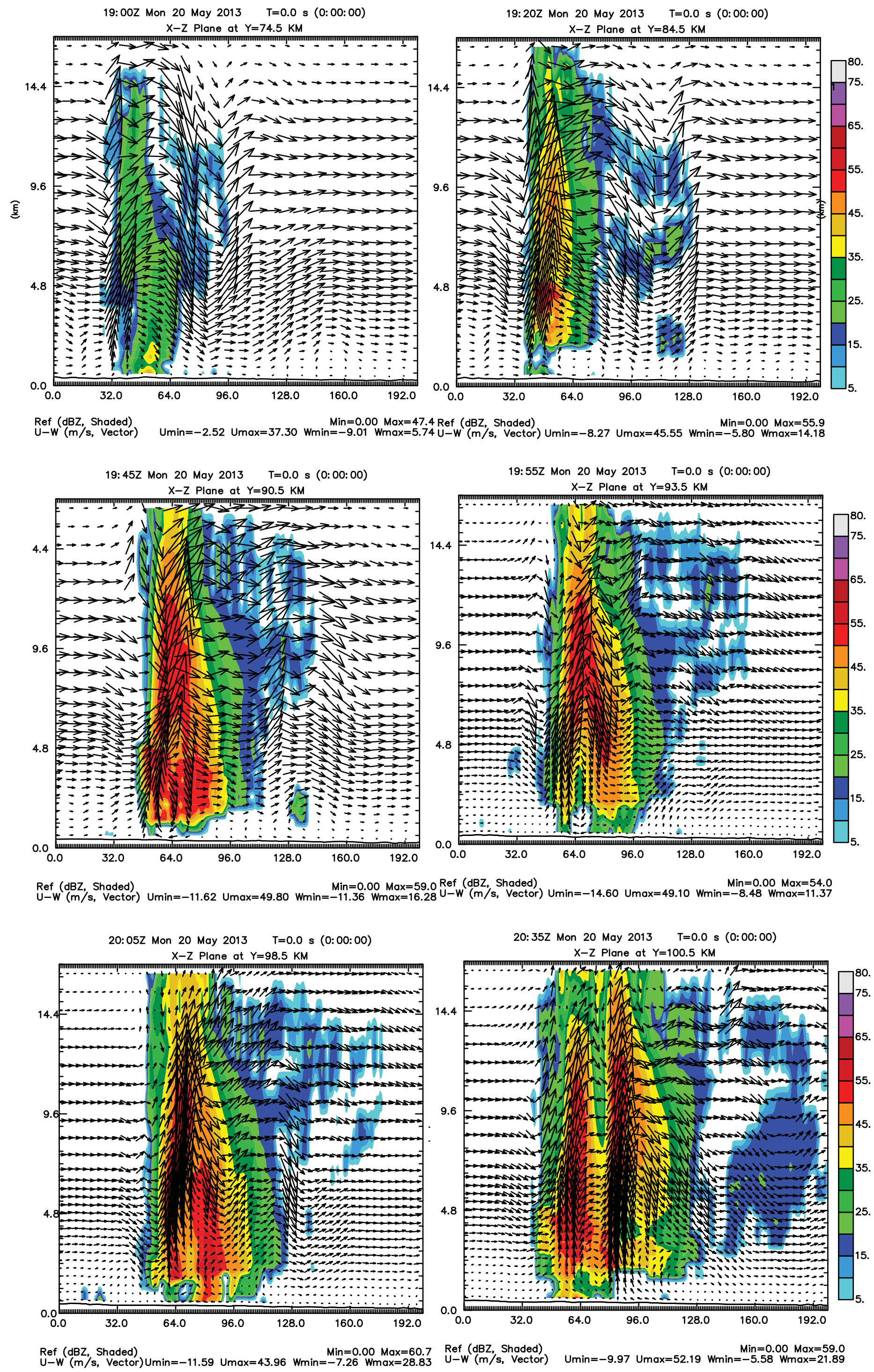

Fig. 3. Wind vectors and reflectivity (color shaded) through a vertical slice in Fig.2 at (a) 1900 UTC, (b) 1920 UTC, (c) 1945 UTC, (d) 0050 UTC, (e) 0055 UTC, and (f) 0100 UTC, 20 May 2013 near Moore, Oklahoma.

Though there were two other nearby strong supercells, but they did not produce strong tornadoes (Fig. 2b, 2c). The Moore tornado touched down at 1956 UTC and our analysis indicated a strong circulation at 1955 UTC analysis (Fig. 2c, Fig. 3c), and also a strong updraft collocated with a reflectivity core. The maximum vertical velocities during tornado touched down time are close to 20 m/s, and maximum vertical vorticity is close to $0.015 s^{-1}$. A very strong mid-level cyclonic circulation persisted until the end of the analysis and the supercell split into two cells around 2020 UTC and the tornado lifted around 2035 UTC.

Fig. 4 and 5 were plotted to show detailed structures of the mesocyclone for the May 20 supercell before and after tornado touchdown. A strong vorticity center moved from southwest to north east direction along the tornado damage path (Fig 4.) The vertical slices through the maximum vorticity indicated a strong, narrow mesocyclone (with threshold value greater than $0.01\ s^{-1}$ for vorticity) extended from about 2 km AGL to about 10 km AGL in the vertical direction. The maximum vorticity became stronger and stronger from 1945 UTC to 2010 UTC and the maximum center gradually moved from above 5 km AGL to 3 km AGL (Fig. 5e), then it rose to above 5 km AGL again before the storm cell split into two cells and the tornado lifted around 2035 UTC.

During this 40 minute period, the reflectivity core underwent an interesting split. A part of the reflectivity core greater than 50 dBz moved to the anvil region with the help of strong downstream winds (Fig. 6). First the reflectivity core was bending towards the anvil area (Fig. 6c), and then the reflectivity core split into two cores (Fig. 6d) and the one in the anvil area gradually reduced in size (Fig. 6e). After this, the violent storm split into two storms and weakened a little bit when the tornado lifted. During this process, the weak echo region (WER) is evident and bounded by a second circulation.

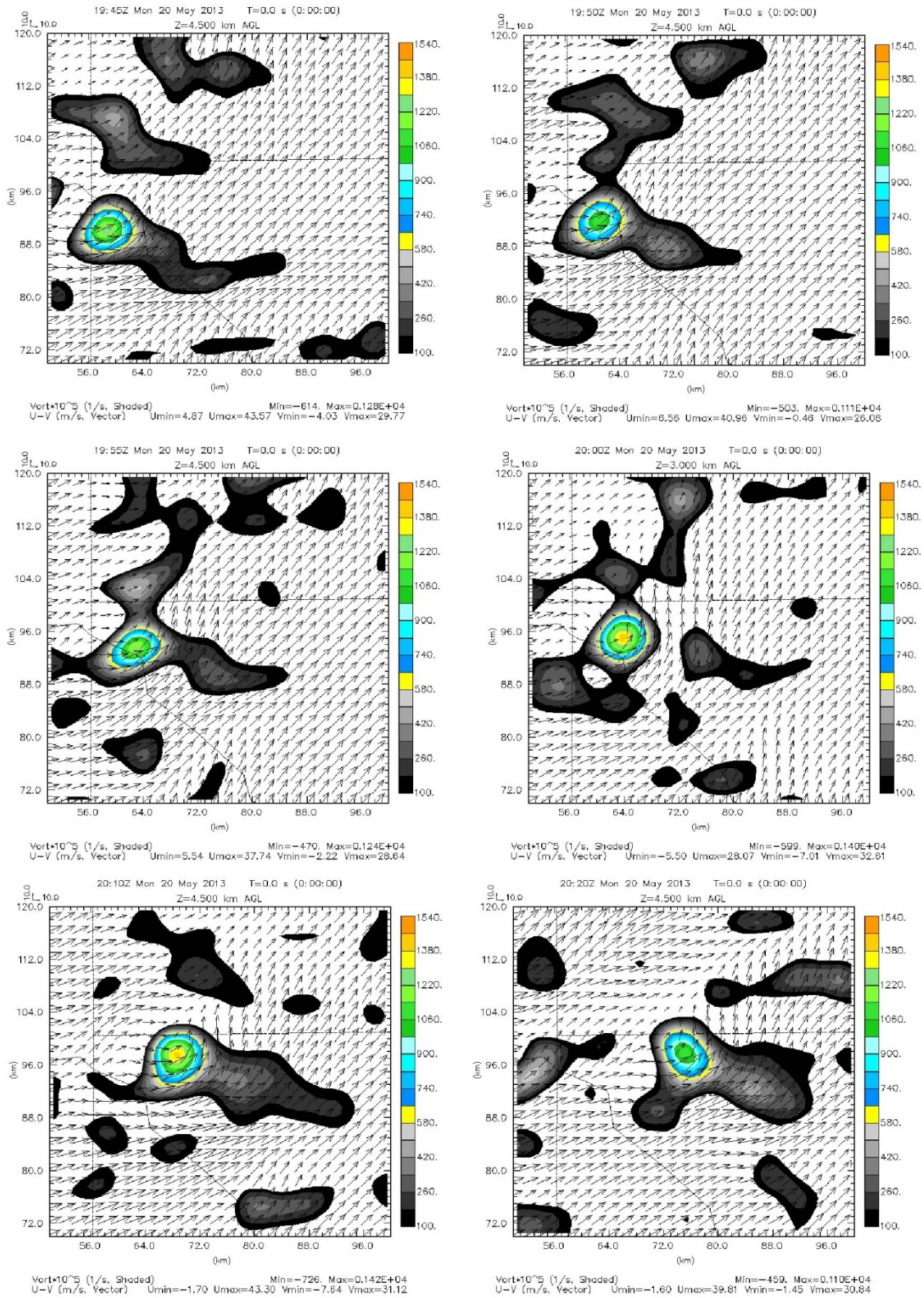

Fig. 4. The horizontal wind vectors, and vertical vorticity (color shaded) at 3 km AGL at (a) 1945 UTC, (b) 1950 UTC, (c) 1955 UTC, (d) 2000 UTC, (e) 2005 UTC, and (f) 02010 UTC, 20 May 2013 near Moore (Zoomed in area in Fig. 2c)

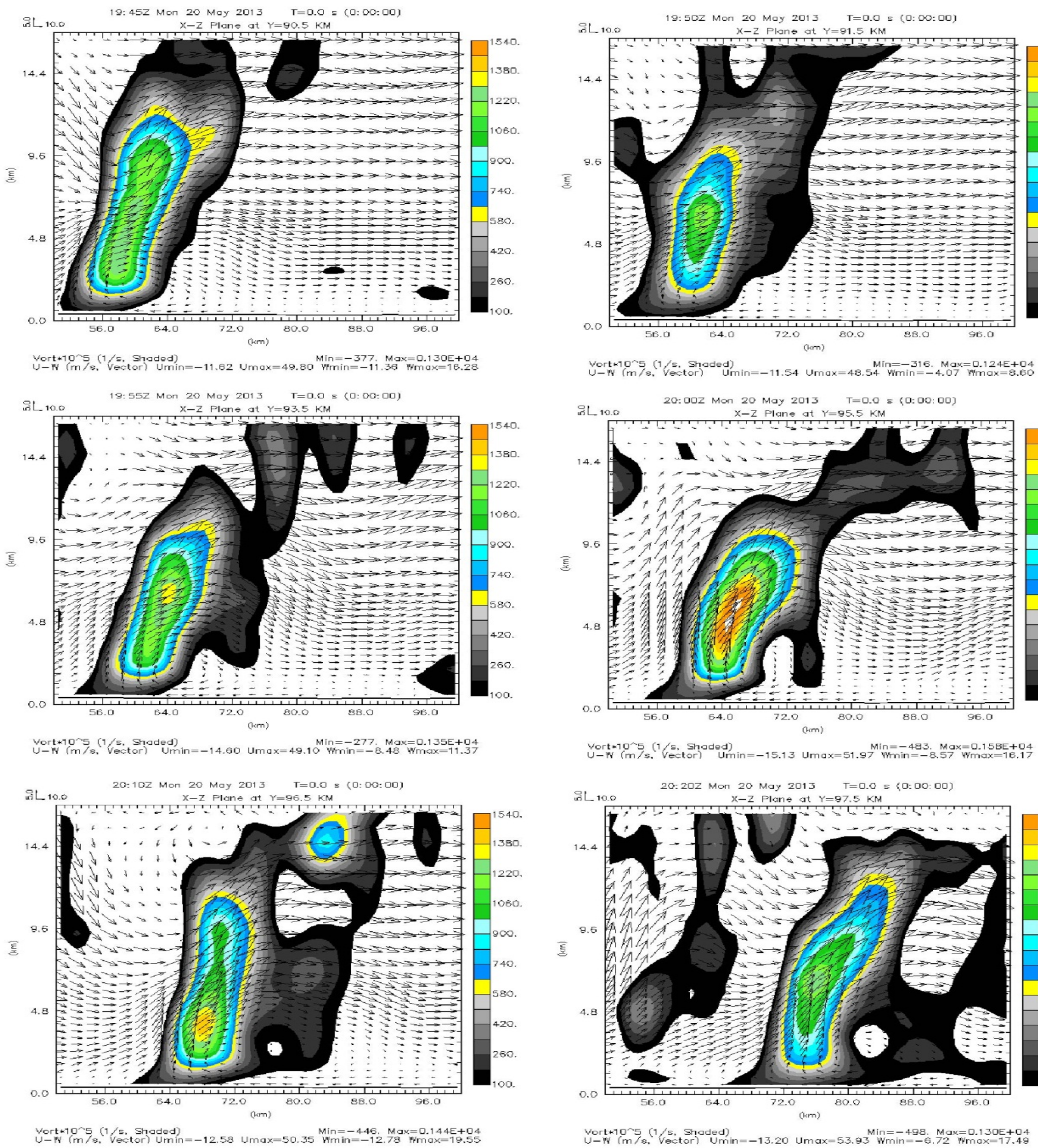

Fig. 5. Wind vectors and vertical vorticity (color shaded) of a x-z slice through maximum vertical vorticity in Fig.2 at (a) 1900 UTC, (b) 1920 UTC, (c) 1945 UTC, (d) 0050 UTC, (e) 0055 UTC, and (f) 0100 UTC, 20 May 2013 near Moore, Oklahoma.

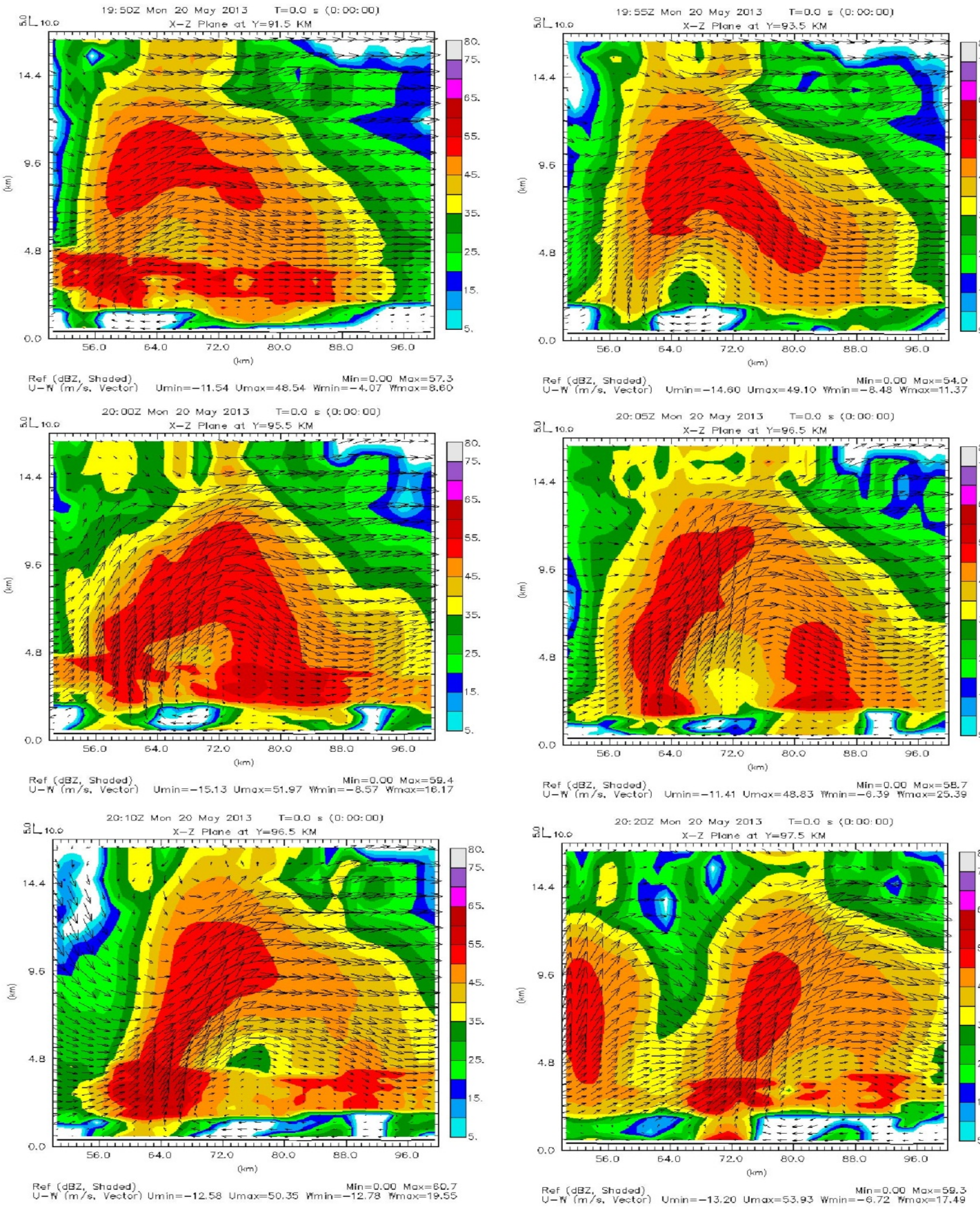

Fig. 6. Same as Fig. 5,but for wind vectors and reflectivity (color shaded).

To easily evaluate the analysis, 3DVAR 0-3 km MSL updraft helicity accumulated over the period from 1900 UTC to 2200 UTC was plotted along with tornado damage paths as determined by the Norman, Oklahoma, National Weather Service Forecast Office. The first part of the track produced by the 3DVAR analysis matched well with the tornado damage path. At this 1 km scale, the 3DVAR analysis cannot resolve a tornado, but the mesocyclone is very intense.

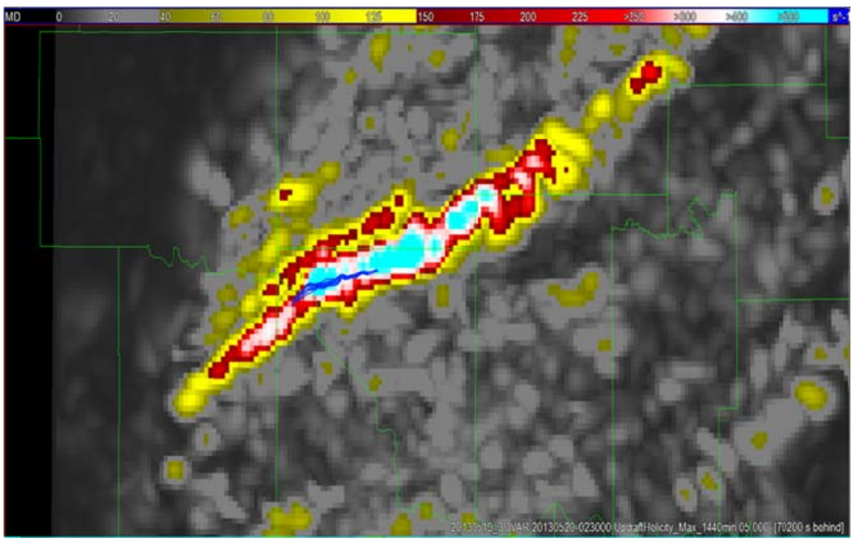

Fig. 7: 3DVAR 0-3 km MSL updraft helicity accumulated over the period from 1900 UTC to 2200 UTC on 20 May 2013 in Central Oklahoma. The dark blue lines indicate tornado damage path as determined by the Norman, Oklahoma, National Weather Service Forecast Office.

4. Summary and future work

In this study, we presented some analysis results for the 20 May 2013 tornadic supercell case using the 3DVAR technique developed for convective scale weather events. For this particular case, the analysis system was running in real-time during the tornado outbreak. The supercell associated with Moore tornado was automatically detected from a floating domain whose location was determined using an automatic domain position system, though this year our system was not evaluated by the NWS forecasters. The supercell related to this particular storm developed very quickly. It took less than 30 minutes for this storm from initiation to become a supercell. After another 25 minutes, the tornado touched down west of Newcastle, Oklahoma. The quickness and violence of the storms like this are very difficult to identify and predict, especially when many supercells appear simultaneously. This kind of 3DVAR analysis product with rotational strength may help NWS forecasters identify the severe weather threat in a timely manner.

Finally, this weather adaptive 3DVAR system has been improved, fully tested and evaluated by National Weather Service forecasters who participated in HWT EWP program in both the 2011 and 2012 spring experiments. The results and feedbacks from the forecasters are reported in Calhoun et al. (2014), and Smith et al. (2014). Future work includes additional data sets into this implementation of the 3DVAR system, such as observations from surface mesonets; and the use of ensemble information to enhance the 3DVAR system; and the direct assimilation of radar reflectivity observations which will be used to initialize storm-scale numerical weather prediction models.

Acknowledgments. This research was primarily funded by the NOAA Warn-on-Forecast project and was partially supported by NSF grant AGS-1341878 to the Coorperative Institute for Mesoscale Meteorological Studies/University of Oklahoma.

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