P5.16 OBSERVED FAILURE MODES OF THE WSR-88D VELOCITY DEALIASING ALGORITHM DURING SEVERE WEATHER OUTBREAKS

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1. INTRODUCTION

The current WSR-88D Velocity Dealiasing Algorithm (VDA) has been in place without significant changes for a number of years (Eilts and Smith, 1990). It has proved itself to be a robust and reliable algorithm for producing operationally useful output. An on-going, study at the Radar Operations Center suggests that the long-term failure rate for the algorithm is somewhere between 1% and 2% (Bob Lee, private communication). Algorithm performance remains good in clear-air and precipitation collection modes when the PRF used for velocity measurement is high enough to produce a reasonably large Nyquist co-interval (~+/- 25 m/s or larger). However, during some severe convective weather outbreaks, VDA failures have been noted.

As part of the ROC/NSSL Technology Transfer MOU (Burgess and Fresch, 2006), multi-year tasks are in progress to 1) improve data quality, including enhancing the effective Nyquist co-interval, and 2) improve or replace the current VDA, improving overall and severe storm performance. One component of the tasks has been to identify VDA failure modes during severe storms and explain their causes. In 2007, National Weather Service (NWS) Regions were asked provide potential cases where VDA failures may have caused problems for forecasters making tornado warning decisions. NWS Central Region responded with two cases from the severe/tornado outbreak in the Midwest on October 18, 2007. The October 18th outbreak was the third biggest of the year for the U.S., producing 45 reported tornadoes with 5 fatalities and 432 severe weather events during the 24 hour period.

This paper will use examples from the October 18th cases to illustrate VDA failure modes and their causes (Section 2). Potential strategies for VDA improvement, both improvements in data quality and algorithm enhancements, associated with current applied research will be given (Section 3). Finally, a summary of WSR-88D dealiasing issues will be given (Section 4).

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2. CASE STUDIES

Utilizing National Climatic Data Center (NCDC) Level II and Level III archives, data were obtained from the Louisville, KY/Ft Knox WSR-88D (KLVX) and from the North Webster, IN WSR-88D (KIWX). Both Level II and Level III data are useful in dealiasing studies since Level II data are archived before VDA application, and Level III data archive the results of VDA application. Commonly occurring dealiasing failures in the data are illustrated by two case studies. Dealiasing issues of these types are directly related to specific warning decision making.

2.1 KLVX Data 2230-2245 UTC 18 Oct 2007

During this example time interval, warning forecasters at the Louisville, KY NWS WFO were dealing with a rapidly developing, isolated supercell that had formed just upwind of the metropolitan Louisville area (Fig 1). The storm already had a mesocyclone aloft (not shown), but an important question remained: had a low-level mesocyclone developed? If a low-level mesocyclone was present, it would signify a significantly greater threat of a tornado threat moving into the western part of the metro area, something justifying a tornado warning. Level III velocities for 2236 UTC (Fig 2; post-VDA image type) illustrate the problem faced by the warning forecaster. At this and other critical times (2228 and 2232 UTC; data not shown), VDA failures (large areas of false maximum outbound (red color in Fig. 2 velocity image)) prevented assessing the character of the low-level mesocyclone. The VDA failures resulted from storm velocity data being mixed with velocity from residual ground clutter and range-folded echoes from storms at long range (purple color). Areas where the mixed residual clutter and real storm velocities produced unexpected velocity gradients that VDA did not handle correctly (see the circled area in Fig 3 (pre-VDA Level II data)). In this case, the warning forecaster, concerned about the tornado potential, even with flawed low-level data, made a good decision and issued a tornado warning for metro Louisville at 2242 UTC (warning polygon shown in Fig. 1), well before a weak tornado struck eastern Louisville at 2310 UTC.

2.2 KIWX Data 0145-0210 UTC 19 Oct 2007

During this example time interval, warning forecasters at the Northern Indiana WFO (North Webster, IN) were dealing with a squall line rapidly moving into the western portion of their county warning area (Fig 4). Although the area was in a tornado watch and conditions were favorable for tornado formation, thus far no tornadoes had occurred with the solid-line segment to the west of the radar. Warning forecasters were scanning storm mid-level velocity data and Mesocyclone Detection Algorithm (MDA) output for signs of mesocyclone development, signaling an enhanced threat of supercell tornado development. Velocity dealiasing problems and confusing MDA data were noted by the forecasters during this interval. Unfortunately, the velocity data seen by the forecasters (Level 3 type images) were not archived. [Only low elevation angle Level III velocity data are archived at NCDC.]. However, the available Level II data (pre-VDA application) provide information on the type of VDA errors that likely occurred. To the southwest of the radar, to the south of the solid line segment, there were breaks in the mid-level data. This was combined with strong winds blowing from the southwest in association with the strong weather system producing the severe weather outbreak and with development of cyclonic circulations on the right flanks of storms. WSR-88D antennas spin clockwise direction as data is collected. As the antenna rotates through the no-echo area, into the area of strong flow (large areas of aliased velocities), it is difficult for VDA to know that the first velocities it encounters are aliased. This occurs even though VDA can be initialized with a fixed wind field, a wind field updated by Velocity Azimuth Display (VAD) output, or wind data from a numerical model. If VDA believes that any areas of outbound (aliased) velocities are real, it will incorrectly flip the adjacent inbound (real) velocities into incorrect very strong outbound velocities. Dealiasing errors probably occurred in this case, confusing the forecasters and MDA. The result was that confidence in the developing rotation signature was not gained early enough to change the existing severe thunderstorm warning into a tornado warning until 8 minutes after a long-track tornado formed. The tornado warning was still valuable because it preceded the by-then-very-strong tornado striking Nappanee, IN by several minutes.

3. WAYS TO REDUCE VDA ERRORS

These two error types (residual ground clutter contamination of VDA for low-level data, and VDA initialization adjacent to data voids for mid-level data) have been seen many times by the authors and others. How can these error types and other types be minimized or eliminated? There are currently several NEXRAD Program developmental projects that will lead to VDA improvements.

3.1 CMD Clutter Filtering

A Clutter Mitigation Decision (CMD) automated algorithm has been developed (Hubbert *et al* 2009a and 2009b) and recently implemented on WSR-88D radars (Ice *et al* 2009). This new algorithm became a part of the WSSR-88D baseline in summer of 2009 and was not being used for the 2007 KLVX example in this paper. The algorithm uses a fuzzy logic framework to identify clutter contamination for each range gate for each low-level scan, providing up-to-the minute estimates of clutter location. This frees radar operators from having to make real-time decisions about changes to clutter filtering parameters in real time during stressful severe weather warning operations. CMD Evaluation and early results from the new software build on all radars suggest that CMD will help reduce VDA failures in ground clutter areas.

3.2 Dual-Polarization Upgrade

Dual-Polarization parameters and particle-type classification algorithms will provide enhanced capability to eliminate non-precipitation return signals and improve overall data quality. These enhancements will benefit VDA by removing ground clutter, bird, bug, and other echoes that cause some VDA failures. Contractor work on the upgrade is progressing, and field deployment is scheduled to begin about a year from now.

3.3 Staggered PRT

A Staggered PRT algorithm has been developed for the WSR-88D (Torres *et al* 2004). It is currently in the process of being implemented in a future software build by ROC and NSSL personnel (Torres *et al* 2009, and Saxion *et al* 2009). Staggered PRT will provide significant increase to the velocity Nyquist co-interval, reducing the amount of dealiasing to be done by VDA and helping to increase algorithm accuracy.

3.4 A New VDA Algorithm

Based on work done by Jing and Wiener (1993), and in part because of increased computer power within the WSR-88D Radar Products Generator (RPG), a new WSR-88D velocity dealiasing algorithm is under development (Witt *et al* 2009). The new algorithm is fully two-dimensional, not limited to adjacent radials or small groups of radials as is the current VDA. Although still experimental and in test mode, the new algorithm already is giving indications of enhanced performance for typical velocity aliasing situations. Not yet proven are enhancements for difficult aliasing situations associated with the large real velocity gradients produced by severe and tornadic thunderstorms. Testing, including tornadic storm cases with types of potential dealiasing failures mentioned in this paper, will continue in 2010.

4. CONCLUDING REMARKS

Correctly dealiasing velocity fields associated with severe and tornadic convective storms is a difficult challenge. The current WSR-88D VDA algorithm has limitations in its ability to correctly dealias such velocity data. Two recurring error types have been observed: 1) errors at low levels associated with ground clutter targets, and 2) errors at mid levels associated with failures to get a good first guess in strong winds at storm right-flank edges. Several potential ways to improve the WSR-88D VDA algorithm exist. Improved data quality in the form of removal of ground clutter and other non-precipitation echoes will help VDA. Larger Nyquist velocity co-intervals will permit less use of VDA and a better starting point for correct dealiasing. Finally, a new, fully two-dimensional VDA is in development, and it may prove to be significantly superior to the current VDA.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Burgess, D.W. and M.A. Fresch, 2006: The ROC/NSSL Technology Transfer MOU: A success story in radar applications technology transfer. 22nd International Conf. on Interactive Information Processing Systems (IIPS), AMS, Atlanta, GA, 29 January – 2 February, 2006, 9.2.

Eilts, M.D. and S.D. Smith, 1990: Efficient Dealiasing of Doppler velocities using local environment constraints. *J. Atmos. Oceanic Tech.*, 7, 118-128.

Hubbert, J. C., M. Dixon, S. M. Ellis and G. Meymaris, 2009a, Weather radar ground clutter. Part 1: identification, modeling, and simulation. *J. Atmos. Oceanic Tech.*, 26, 1165-1180.

Hubbert, J. C., M. Dixon, S. M. Ellis and G. Meymaris, 2009b, Weather radar ground clutter. Part 2: Real-time identification and filtering. *J. Atmos. Oceanic Tech.*, 26, 1181-1197.

Ice, R.L., R. D. Rhoton, J. C. Krause, D. S. Saxion, O. E. Boydstun, A. K. Heck, J. N. Chrisman, D. S. Berkowitz, W. D. Zittel, and D. A. Warde, 2009: Automatic clutter mitigation in the WSR-88D, design, evaluation, and implementation. 34th Conf. on Radar Meteor., AMS, Williamsburg, VA, 5 Oct-9 Oct, 2009. Paper P5.3.

Jing, Zhongqi, and G. Wiener, 1993: Two-dimensional dealiasing of Doppler velocities. *J. Atmos. Oceanic Tech.*, 10, 798-808.

Saxion, D.S., R.D. Rhoton, R.L. Ice, J.C. Krause, O.E. Boydstun, W.D. Zittel, S.M. Torres, and D.A. Warde. New science for the WSR-88D: Staggered PRT implementation on the SIGMET RPV8. 34th Conf. on Radar Meteor., AMS, Williamsburg, VA, 5 Oct-9 Oct, 2009. Paper P5.1.

Torres, S. M., Y. F. Dubel, and D. S. Zrnić, 2004: Design, implementation, and demonstration of a staggered PRT algorithm for the WSR-88D, *J. Atmos. Oceanic Tech.*, **21**, 1389-1399.

Torres, S., D. Zittel, D. Saxion, 2009: Update on deployment of staggered PRT for the NEXRAD Network. 25th International Conf. on IIPS, Phoenix, AZ, AMS, Paper 11B.2.

Witt, A., R.A. Brown, and Z. Jing, 2009: Performance of a new velocity dealiasing algorithm for the WSR-88D. 34th Conf. on Radar Meteor., AMS, Williamsburg, VA, 5 Oct-9 Oct, 2009. Paper P4.8.

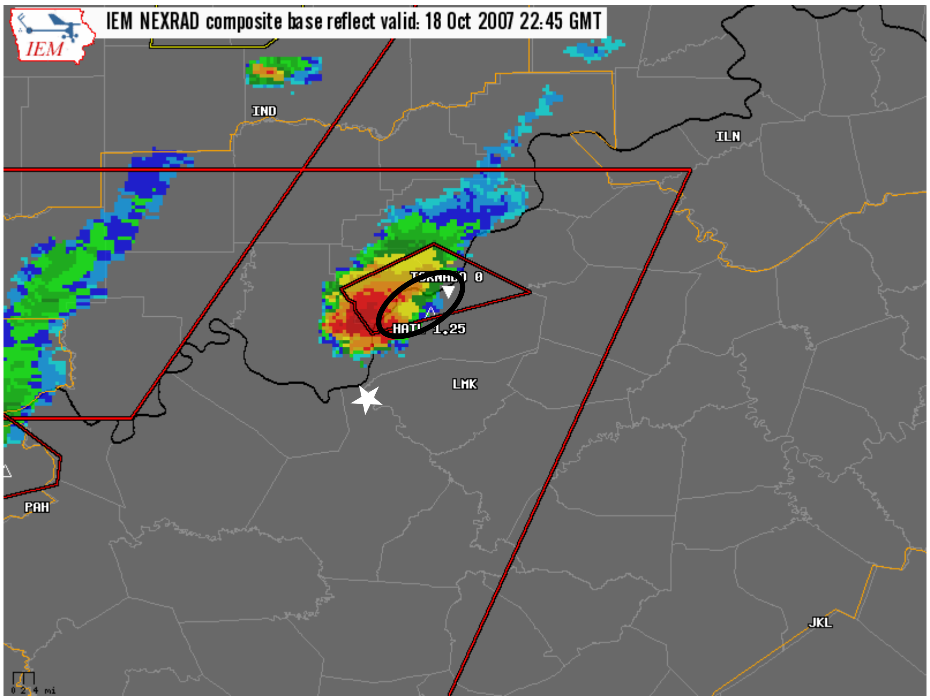

Figure 1. Radar echo and just-issued tornado warning (polygon outlined in red) at 2245 UTC on 18 Oct 2007. Black oval is approximate location of the Louisville, KY metropolitan area; white star is approximate location of KLVX radar; longer red line segments mark tornado watch areas; location of tornado and hail (1.25") are marked. Image from Iowa State Univ. website, Iowa Environmental Mesonet (IEM).

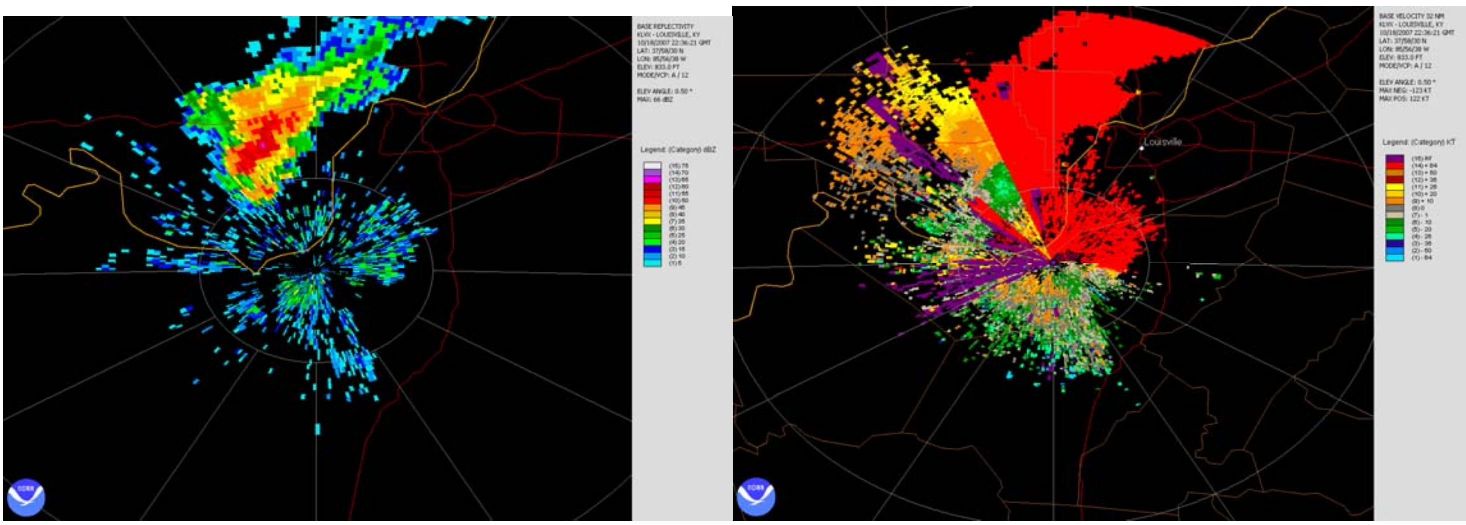

Figure 2. Level III KLVX Reflectivity(left) and Velocity (right) at 2236 UTC on 18 Oct 2007, 0.5 deg. elevation.

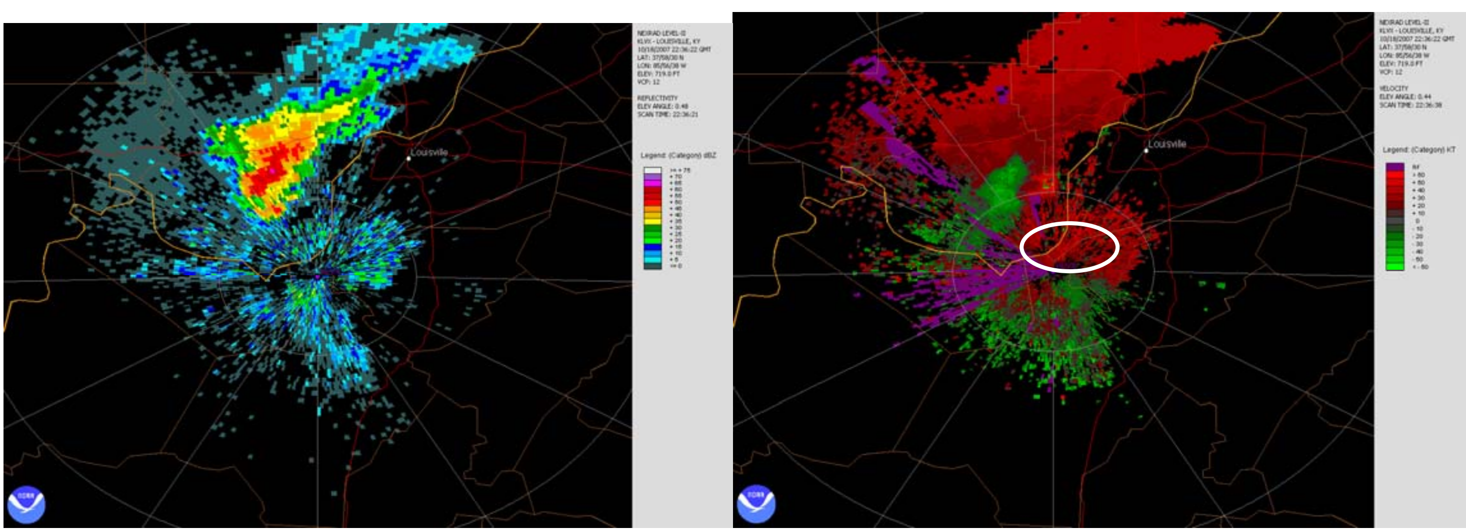

Figure 3. Level II KLVX Reflectivity (left) and Velocity (right) at 2236 UTC on 18 Oct 2007, 0.5 deg. elevation. White oval marks approximate area of disturbed velocities/velocity gradients causing VDA algorithm failure.

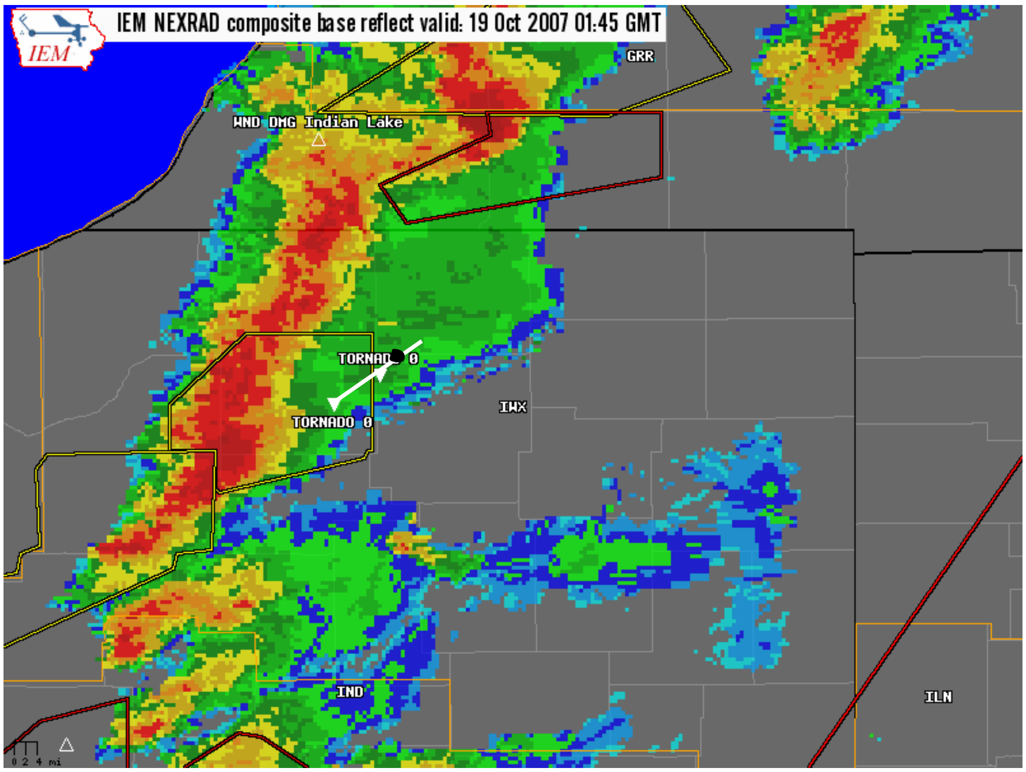

Figure 4. Radar echo and just-issued severe thunderstorm warning (polygon outlined in orange and to the west of KIWX radar) at 0145 UTC on 19 Oct 2007. White line and triangles are approximate locations of tornado track; black circle is approximate location of Nappanee, IN (F3 damage); longer red line segments mark tornado watch areas. Image from Iowa State Univ. website, Iowa Environmental Mesonet (IEM).

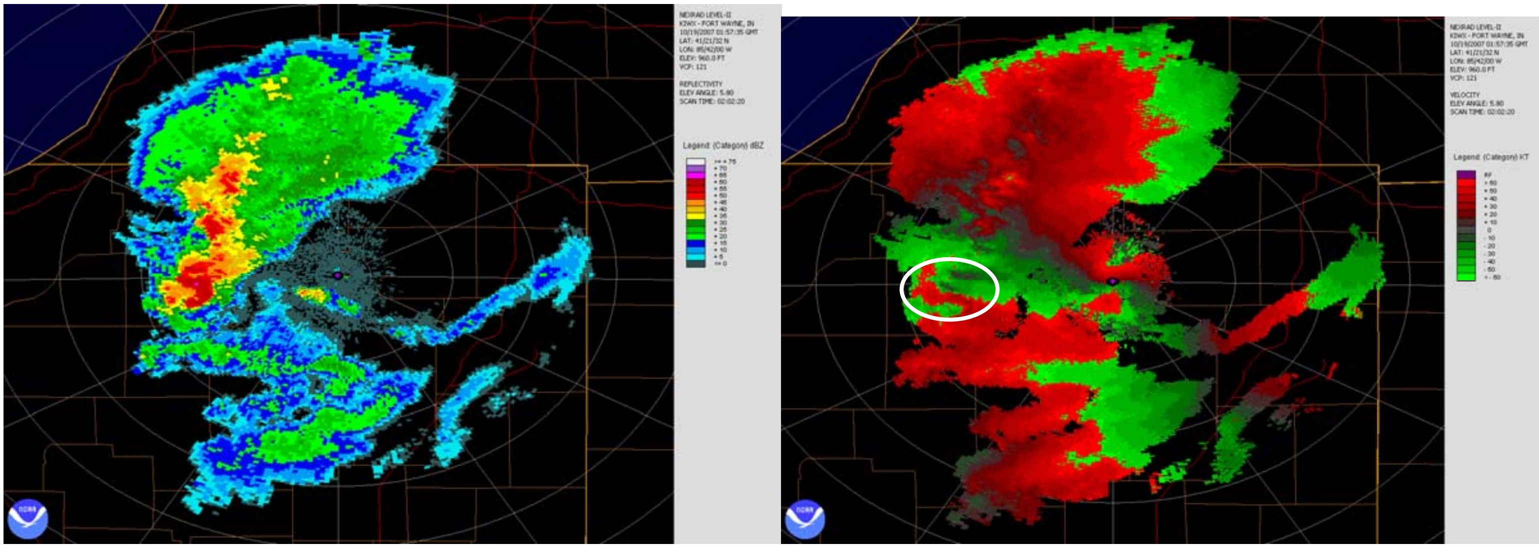

Figure 5. Level II KIWX Reflectivity (left) and Velocity (right) at 0157 UTC on 19 Oct 2007, 5.8 deg. elevation. White oval marks area of developing mesocyclone. Note that all red color shades to the south and west of the radar are aliased (radial component > 50 kt toward the radar), and green color shades to the north and east of the radar are aliased (radial component >50 kt away from the radar).