P5.2 Overview of the 2005 and Spring 2006 WDSS-II Demonstration at WFO St. Louis

Douglas E. Tilly and Ron W. Przybylinski
NOAA / National Weather Service
St. Louis MO

Travis M. Smith
CIMMS / Univ. of Oklahoma
NOAA/ National Severe Storms Laboratory
Norman, OK

1. Introduction

The National Severe Storms Laboratory (NSSL) regularly develops new techniques and display systems to assist forecasters make better and faster severe weather warning decisions. These techniques, often in the form of new radar applications and multiple-platform products are evaluated during severe weather warning operations. From spring of 2005 through the summer of 2006, Weather Forecast Office (WFO) St. Louis (LSX) has participated in the testing and evaluation of the Warning Decision Support System – Integrated Information (WDSS-II). One Linux display workstation running WDSS-II was provided by Central Region Headquarters allowing warning forecasters to interrogate output from many experimental products. Products from WDSS-II were evaluated from 28 severe weather episodes including 6 cool and transitional seasonal cases.

WDSS-II uses archive level II data from multiple radars and integrates the data to form a number of 3-D products. Some of these products can be used to fill in missing data from a single radar location. Multi-radar products combine the 2-D data from the available radars to make a final 3-D product that is updated every minute (Lakshmanan et al. 2006). This rapid update can be beneficial in the warning decision process, especially when rapidly developing thunderstorms are close to the radar location. Sampling issues are also improved when using merged radar data. Using data from multiple radars increases the vertical resolution at long ranges solving problems due to effects such as beam spreading or blockage. This increased vertical resolution can improve the accuracy of shear and hail algorithms.

During warning operations at WFO LSX, the most widely used products included: 1) reflectivity at -20° C isotherm surface, 2) height of the 50 dBZ echo top, 3) Linear Least Squares Derivative (LLSD) shear, 4) 0-3 km LLSD shear, 5) merged 0-3 km azimuthal shear and 6) cross-sectional data of base reflectivity, base velocity and LLSD shear. The majority of cases that were sampled during the 2005 – 2006 convective season fell in the multicluster or supercell group while only five quasi-linear convective system (QLCS) events were surveyed. An overview of the following products including: 1) -20°C isotherm surface, 2) height of the 50 dBZ echo top, 3) 0-3 km azimuthal shear from a single radar and merged 0-3 km LLSD shear and 4) cross-sectional capabilities will be presented. Discussion will include strengths and weaknesses of the product as well as case examples of the product.

2. Products evaluated:

a. Reflectivity at -20°C isotherm

The hail product most widely used, and possibly the best severe hail prognostic tool, is the reflectivity at the -20°C isotherm. This product is derived from merging reflectivity data from multiple radars and using near-storm environment (NSE) data. The NSE is derived from the Rapid Update Cycle (RUC) model output data at a 60 minute interval onto a 20 km grid. The algorithm uses the merged reflectivity data and determines the maximum value at the -20°C isotherm height, which is determined by using NSE data.

Once this reflectivity data is displayed onto a grid, determining the severity of a thunderstorm can be done more quickly. The use of this product can aid in increasing warning lead time, while decreasing the false alarm rate (FAR). It is believed this is possible because the algorithms ingest environmental data (i.e., NSE data) that has a much higher spatial and temporal resolution than upper air data.

A possible downside of this product is that it is dependent upon the accuracy of model data. If the model data has large errors, the reliability of this product may be compromised. However, a case displaying this type of situation never occurred during the nearly two years the WDSS-II resided at WFO LSX. This may be due to the variability of this product. Critical thresholds from this algorithm will have daily variances as well as seasonal changes, just as other severe hail signals (e.g., VIL of the day). Therefore model errors may not be evident in real-time events.

On 11 March 2006, several supercells tracked across portions of Missouri and Illinois spawning 9 tornadoes and countless reports of large hail within the WFO LSX County Warning Area (CWA). Figure 1 shows the maximum reflectivity on the -20°C isotherm at 2200 C

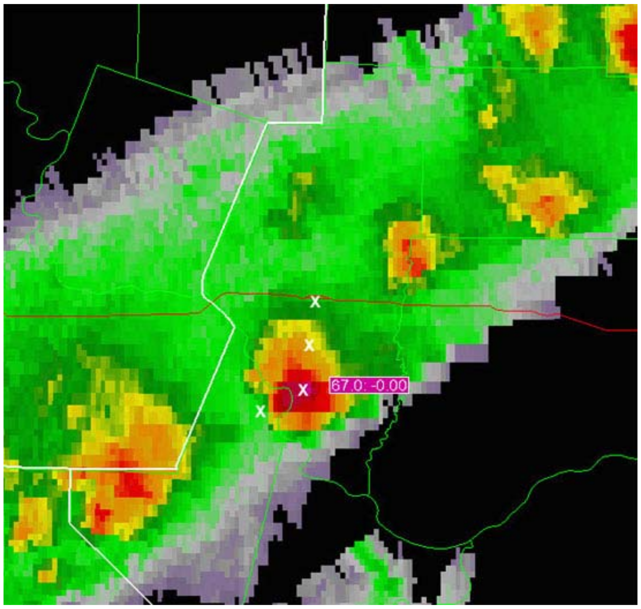

Fig. 1. Reflectivity on the -20°C isotherm. for 2200 on 11 March 2006. (x) marks location of hail 4.4 cm diameter and greater.

UTC (here after all times in UTC). Each "X' marks the approximate location of hail reports within 5 minutes of the captured image. Images similar to this one proved helpful for verification calls to spotters and the general public during post storm evaluation. This data also proved helpful during this outbreak allowing the warning coordinator an overview of potentially severe storms within the CWA.

b. Height of the 50 dBZ Echo Top

Another hail prognostic tool derived from merged reflectivity data is the height of the 50 dBZ echo top. This algorithm uses merged reflectivity to determine the maximum height at which a 50 dBZ echo is observed. Similar to other multiple radar products, this algorithm is also updated every minute, providing a higher temporal resolution than of a single radar alone. This higher temporal resolution allows faster updates to warning forecasters, which in turn can increase warning lead time. However, the same forecasting issues are still present as those associated with conventional radar displays. Therefore large differences in current verification scores are not likely to occur while using this product.

This product, along with the reflectivity on the -20°C isotherm, became invaluable during large severe weather outbreaks at WFO LSX. These products allow multiple warning forecasters to focus on the most dangerous storms, while another forecaster can quickly scan the entire county warning area (CWA) for other possible severe storms.

On 13 June 2005 a line of supercells tracked across the WFO LSX CWA and eventually merged into a bow echo over Illinois. The system produced a large swath of significant hail over parts of eastern Missouri and several small tornadoes over parts of southwest Illinois. This case

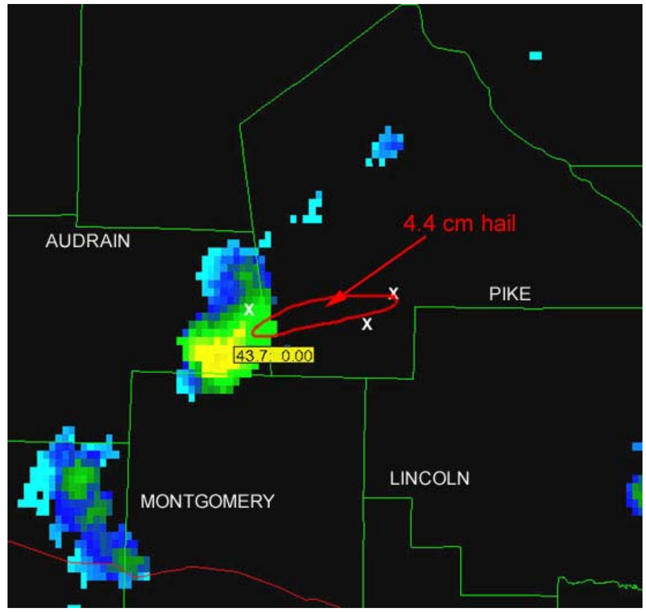

Fig. 2. Height of the 50 dBZ echo across portions of eastern Missouri. Most of the hail In this area was determined after a post storm damage survey.

was also captured well by WDSS-II merged radar products (Fig. 2). In this figure, a supercell produced hail up to 5.0 cm across portions of southwest Pike County Missouri. Most of the hail in this area was determined after a post storm damage survey.

c. LLSD Shear Diagnostic Products (0-3 km layer)

Present techniques today in the WSR-88D search for patterns of vertically correlated azimuthal shear from single Doppler velocity data. These techniques have shown to have short-falls in estimating the location, size and strength of mesovortices (Mitchell et al 1998; Stumpf et al. 1998). These techniques can also produce false detections along with non-rotational features. Another method of allowing the warning forecaster to view the mesovortex strength is through the means of LLSD azimuthal shear. Elmore et al. (1994) has found that LLSD azimuthal and radial shear calculations provides more accurate calculations of true vortex strength, and better identifies the location of the shear feature.

The 0-3 km layer LLSD (and merged 0-3 km LLSD) shear products were used during warning operations. Most of the events that occurred during the 2005-2006 severe weather seasons fell under the supercell – multicell cluster category while only a fraction of convective line – bow echo type cases. All of these cases were archived for further study and analyses. One of the goals in our evaluation of WDSS-II was to examine the capabilities of the product 0-3 km LLSD and merged 0-3 km LLSD shear products during real-time warning operations and study mesovortex evolution associated with convective lines and bow echoes. During this period only five convective line cases were archived and studied with three cases occurring during the spring and summer 2006 convective season. Tornadic and non-tornadic mesovortices were associated with four of the five events. Table 1 provides a listing of QLCS cases and mesovortex distances from KLSX WSR-88D site.

Cases	**Mesovortex distances from KLSX WSR-88D**
June 13, 2005 bow echo	105 – 115 km
August 13, 2005 bow echo	< 100 km
April 2, 2006 QLCS	< 90 km and between 125 – 145 km
June 22, 2006 bow echo	> 110 km
July 21, 2006 bow echo	< 150 km

Table 1: Distance of QLCS mesovortices from WFO KLSX during the Spring 2005 through Summer 2006 convective season.

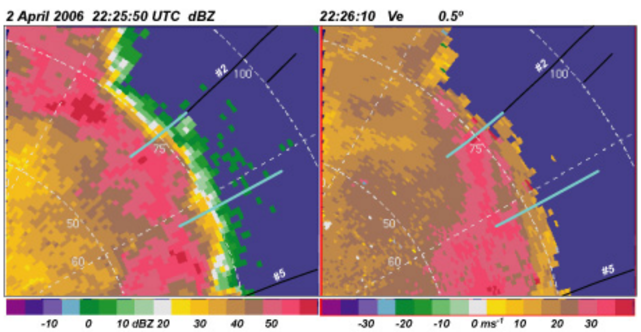

Fig. 3. KLSX reflectivity (dBZ) (left) and base radial velocity (m s^{-1}) (right) in plan view (0.5°) for 2226 UTC. Thin solid black lines represent the location of mesovortex tracks #2 and #5. Thin solid blue lines are superimposed on mesovortex tracks.

The 02 April 2006 quasi-linear convective system (QLCS) event provided both non-tornadic and tornadic mesovortices which were close and at distant ranges from the KLSX WSR-88D. Damage assessment revealed that much of the tornadic damage fell in the F0 – F2 intensity. Two fatalities and twenty injuries occurred over parts of the St. Louis metro area and areas over southwest Illinois (See Przybylinski et al 2006 elsewhere in this volume). This case was very challenging for the warning forecasters since many of the mesovortices revealed weak to moderate intensity rotational characteristics and very small core diameters (less than 0.7 km).

Figure 3 shows the reflectivity – base velocity – mesovortex track overlay for Mesovortex #2 (MV 2) and 3 (MV#3) over parts of Macoupin and Montgomery counties in southwest Illinois for 2226. The distance between these mesovortices and WSR-88D from KLSX was approximately 68 – 144 km (northeast of KLSX). A snapshot of the LLSD product (0-3 km layer) for 2226 is shown in **Fig. 4.** The higher magnitudes of shear (darker red region) shown in figure 4 points to the location of tornadic mesovortex #2 (MV 2). The darker red areas are often identified along the leading side of bowing convective lines. Weak tornadoes were occurring at this time and were causing damage to machine sheds, other farm buildings and large trees over parts of

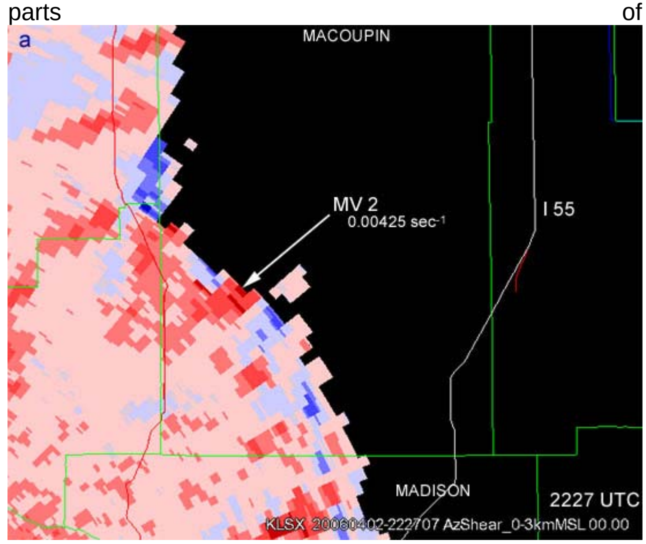

Fig. 4. LLSD (0-3 km) shear product for 2227 UTC 02 April 2006.

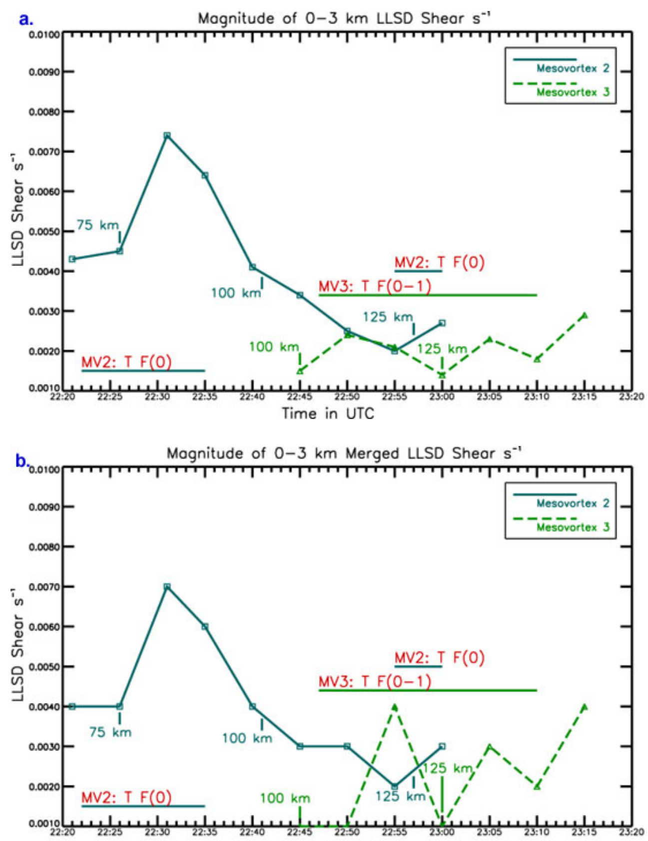

Fig. 5. Time history of the magnitude of a) LLSD shear (0-3 km), b) merged LLSD shear (0-3 km) for MV 2 and 3.

southwest Macoupin County Illinois. A time history of the magnitude of 0-3 km LLSD shear from KLSX and 'merged' LLSD shear (KLSX and surrounding WSR-88D sites) for MV 2 and MV 3 are shown in **Figs 5a and 5b.** Our discussions will focus on MV#2. During the early stages of MV#2, the magnitudes of LLSD rapidly increased from 2225 to 2230 and peaked to a value of 0.0074 s-1 at 2230. Tornadic activity occurred just after 2221 and continued to 2235. The 'merged' LLSD shear product showed a similar trend. Przybylinski et al. (2000) and Atkins et al. (2005) have shown that tornadoes associated with convective line (bow echoes) may occur during the period when the mesovortex ascends to greater heights while rotational strength increases within the lower 2 or 3 km. The LLSD products appeared to show this characteristic. During the subsequent two volume scans (2235 and 2240), LLSD shear values significantly dropped while the last of a series of three tornadoes ended at approximately 2235. A second minor rise in the magnitude of LLSD is noted between 2255 This trend was also noted in the merged product as well. A weak tornado (F0 intensity) occurred over extreme northern Montgomery County, Illinois at this time and caused machine shed and other farm building damage 9 – 10 km east of Farmerville Illinois.

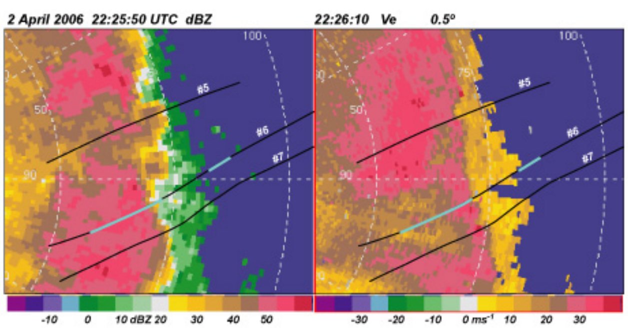

Fig. 6. Same as figure 3 except for 2216 UTC.

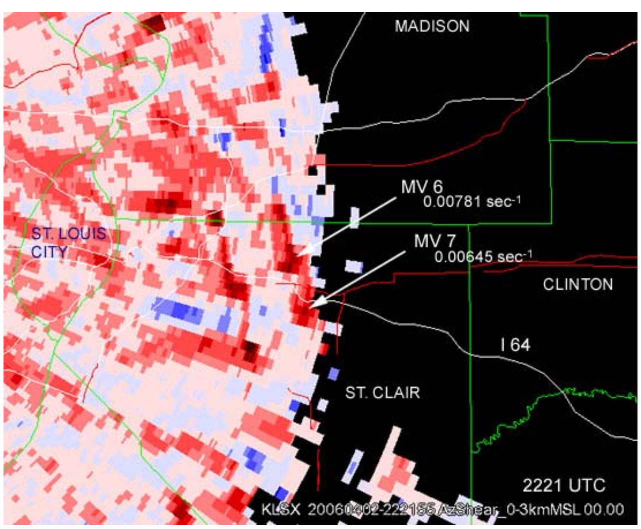

Fig. 7. Same as figure 4 except for 2221 UTC east of the city of St. Louis over St. Clair and Madison counties in southwest Illinois.

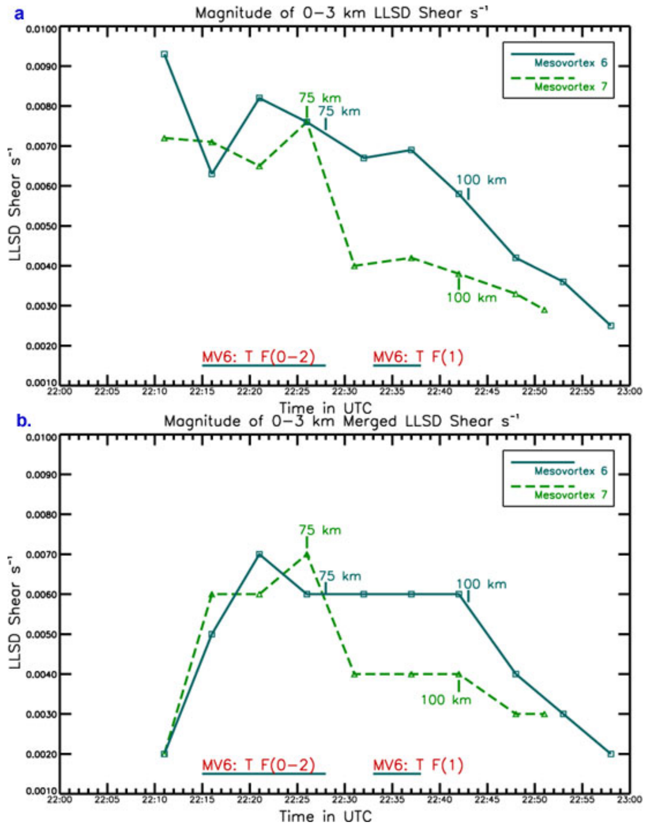

Fig. 8. Same as figure 5 except for MV 6 and 7. **a)** 0-3 km LLSD shear **b)** 0-3 km merged LLSD shear.

Further south, two tornadoes caused F0-F2 damage just east of downtown St. Louis over northern St. Clair and southeast Madison counties in southwest Illinois. Base reflectivity and velocity with mesovortex track overlay for MV's 6 and 7 for 2216 are shown in **Fig. 6.** The distance between these mesovortices and WSR-88D KLSX radar was approximately 50 – 95 km (east-northeast). Another snapshot of 0-3 km LLSD 2221 is shown in **Fig. 7.** The darker red regions along the leading edge of this field show the locations of MV's 6 and 7. Time histories of the magnitude of LLSD and 'merged' LLSD for MV's 6 and 7 are shown in figures **8a and 8b.** Both mesovortices formed very rapidly over the western part of St. Clair County and exhibited high magnitudes of LLSD during the formative stages. From 2210 through 2225, MV 6 showed generally slightly higher magnitudes of LLSD shear compared to MV 7 and spawned a tornado which caused F0 – F2 damage to businesses, residential and rural areas over parts of northern St. Clair County including the communities of Fairview Heights and O'Fallon, Illinois. One fatality and several injuries occurred along the tornado's damage path. At this same period, MV 7 also showed high LLSD shear values, however wind damage was reported along the path of the mesovortex. Curiously, MV 6 continued to maintain shear values above 0.0060 s-1 through 2240 while magnitudes of shear with MV 7 dropped to 0.0040.at 0030. MV 6 spawned a second tornado (F1 damage) southwest and south of Highland Illinois in southeast Madison County between 2230 and 2240. Several residential homes and farmsteads were damaged by the tornado. It is interesting to point out that the majority of the damage was along the path of each mesovortex.

d. Cross-section capabilities

When using WDSS-II in real-time warning operations, WFO LSX forecasters discovered the powerful tool and capabilities of viewing vertical cross-sections of base reflectivity, base velocity and LLSD shear. Not only could forecasters view the vertical structure of the storms, but also have the capability to move the cross-section through an isolated supercell or a convective line in real time. Vertical cross-sections of base velocity and LLSD shear products proved to be *very useful* and gave forecasters another dimension in visualizing the structure of mesoscale airflow currents along the trailing flank of a bowing convective line or observing the change in rotational characteristics (e.g. strength and depth) of a mesovortex associated with a supercell.

On 11 May 2005, a cluster of strong thunderstorms with a few embedded supercells formed during the mid to late afternoon over central Missouri including the city of Columbia. These storms shown in figure 9 at 2047 were approximately 130 to 170 km west of the WSR-88D KLSX radar. The cross-section of azmiuthal shear (AzShear) of one supercell just west of Columbia shows the strongest LLSD shear (dark red region) betweem the 4.5 to 5.0 km level (**Fig. 10**). This region of strongest rotation did not descend to lower levels within the overall mesovortex during the following twenty minutes. Rather the strongest region of AzShear weakened as the storm weakened northeast of Columbia. Large hail and damaging winds occurred with this storm west and northwest of Columbia.

Figure 11 shows two bow echo systems over parts of eastern Missouri and southwest Illinois during the afternoon of 13 August 2005 at 2259. The first bow echo produced extensive wind damage over parts Franklin, St. Louis and Jefferson counties in eastern Missouri and east of St. Louis in St. Clair and Madison counties in southwest Illinois. Over 250,000 customers in the St. Louis county area alone were without power for several days. As the first bow echo moved into parts of southwest and south-central Illinois, a second bow echo was approaching the greater St. Louis metropolitan area from the west. The question among warning forecasters at this time focused upon depth of the shallow cool stable layer laid from the first bow echo. Was this layer sufficiently deep to prevent damaging winds from occurring over the metro area a second time? The second bow echo produced scattered wind damage as it moved across central sections of Missouri earlier in the afternoon. The vertical cross-section of base velocity at 2300 (**Fig. 12**) from KLSX southwest through the second bow shows a slightly sloping but well defined mesoscale rear inflow jet. The narrow channel of 30 m s-1 and greater (white area) outlines the stronger core of the RIJ. Continuous monitoring of the feature from vertical cross-sections reveals that the RIJ core remained elevated as it moved across the St. Louis metro area. Severe thunderstorm warnings were not issued for the metro area based on the elevated RIJ and the likely

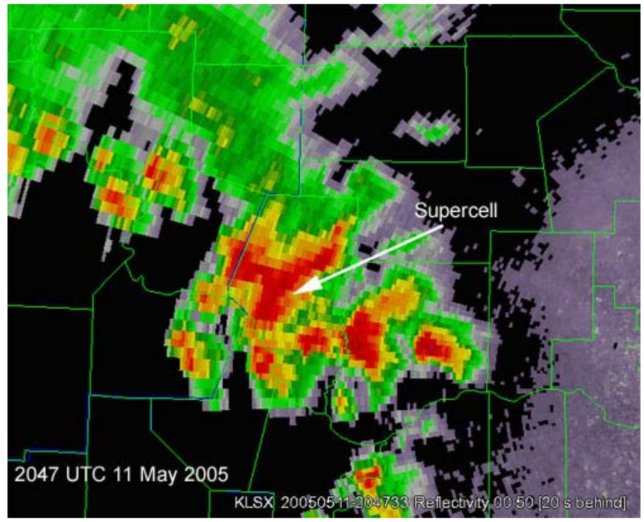

Fig. 9. Plan view reflectivity image (0.5° slice) from KLSX at 2047 UTC.

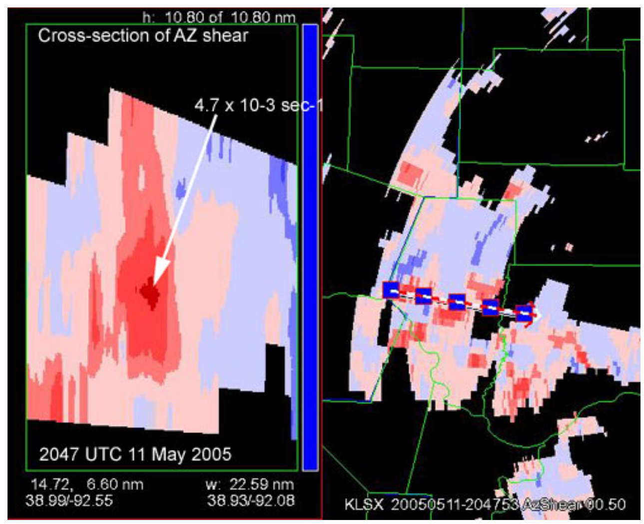

Fig. 10. Cross-section of LLSD shear at 2047, 11 May 2006.

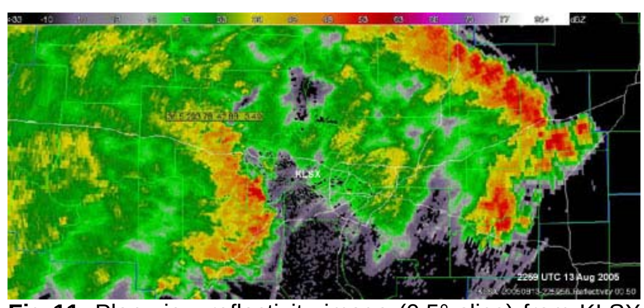

Fig 11. Plan view reflectivity image (0.5° slice) from KLSX at 2259 UTC 13 August 2005.

shallow stable layer from the first bow echo. Measured and estimated wind gusts along the leading side of the second bow echo was 15 to 20 m s-1 over the greater St. Louis metro area.

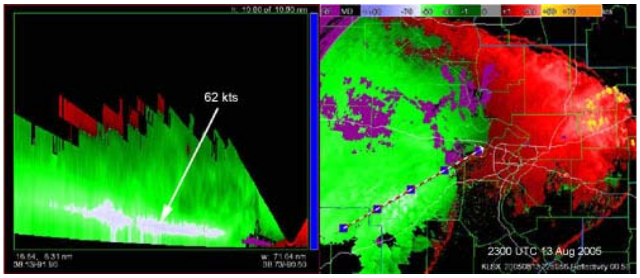

Fig. 12 Cross-section of base velocity (viewing southwest) at 2300 UTC 13 August 2006.

III. Summary

During the spring of 2005 through the summer of 2006, WFO LSX meteorologists evaluated new WDSS-II algorithm output and display techniques during severe weather warning operations. Many of the WDSS-II products were used to aid in warning decision making.

Hail algorithm products including the -20°C surface, proved to be a very useful in determining which storms may contain large hail. The LLSD and merged LLSD products were used to identify the strength of mesovortices and were evaluated for supercell, multicluster and convective line cases. Local regions of high shear within supercell storms and along the leading edge of convective lines helped forecasters identify the location and intensity of mesovortices.

The cross-sectional capabilities in WDSS-II proved to be very useful in a number of ways. Monitoring supercell strength and depth changes with LLSD shear in cross-section mode over time gave forecasters another dimension concerning the evolution of mesovortices. Viewing the structure of the mesoscale rear inflow jet within QLCSs allowed forecasters to determine if the jet would remain elevated or descend resulting in potential wind damage. With the new capabilities of WDSS-II, additional studies will be needed to further understand the strengths (and limitations) of WDSS-II products and fine tune these products. WDSS-II has brought another dimension to the warning and forecast process at WFO LSX. We are looking forward to these new capabilities to be implemented in the future on the Advanced Weather Information Processing System (AWIPS) platform.

IV. Acknowledgements

Special thanks goes to Mr. Peter Browning and Mr. Thomas Schwein at Central Region Headquarters for the equipment and Mr. Travis Smith at National Severe Storms Laboratory for the tutorial and software support during the test and evaluation. Thanks also goes to Mr. Benjamin Sipprell at WFO St. Louis for the development of the time histories of the magnitude of LLSD (0-3 km layer) shear traces. We are also grateful to Mr. Steven Thomas (MIC) WFO St. Louis for support of the WDSS-II project test and evaluation.

V. References

Atkins N.T., C.S. Bouchard, R.W. Przybylinski, R.J. Trapp, and G.K. Schmocker, 2005: Damaging surface wind mechanisms within the 10 June 2003 Saint Louis Bow Echo during BAMEX. *Mon. Wea. Rev.* **133**, 2275 – 2296.

Elmore, K.M. D.D. Albo, R.K. Goodrich, and D.J. Peters, 1994: NASA/NCAR airborne and ground-based wind shear studies. Final report. Contract mo. NCC1-155. 343pp.

Lakshmanan, V., T.M. Smith, K. Hondl, G.J. Stumpf, and A. Witt, 2006 (in press): A real-time, three dimensional, rapidly updating, heterogeneous radar merger technique for reflectivity, velocity and derived products. *Weather and Forecasting.*

Mitchell, E.D., S.V. Vasiloff, G.J. Stumpf, A. Witt, M.D. Eilts, J.T. Johnson, and K.W. Thomas. The National Severe Storms Laboratory Tornado Detection Algorithm. *Wea. Forecasting,* **13,** 352-366.

Przybylinski, R.W., G.K.Schmocker, and Y.-J Lin, 2000: A study of storm and vortex morphology during the intensifying stage of severe wind mesoscale convective systems. Preprints, *20^{th} Conf. on Severe Local Storms.* Orlando, FL, Amer. Meteor. Soc., 173-176.

Smith, T.M., K.L. Elmore, G.J. Stumpf and V. Lakshamanan, 2003: Detection of rotation and boundaries using two-dimensional, local, linear least squares estimates of velocity derivatives. Preprints, *31^{st} Conf. on Radar Meteorology,* Amer. Meteor. Soc., Seattle, WA 310-313.

Stumpf, G.J. A.Witt, E.D.Mitchell, P.L. Spencer, J.T. Johnson, M.D. Eilts, K.W. Thomas, and D. W. Burgess, 1988: The National Severe Storm Laboratory Mesocyclone Detection Algorithm for the WSR-88D. *Wea. Forecasting,* **13,** 304-326.