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# WARNING DECISION SUPPORT SYSTEM—INTEGRATED INFORMATION (WDSS-II). PART I: MULTIPLE-SENSOR SEVERE WEATHER APPLICATIONS DEVELOPMENT AT NSSL DURING 2002

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## 1. Introduction

The National Severe Storms Laboratory has played the primary role in the development and evaluation of National Weather Service severe weather applications for the WSR-88D Doppler radar. NSSL developed many of the primary detection algorithms for the radar, and is currently developing improvements to these algorithms. The traditional WSR-88D severe weather algorithms have been designed for use with a single-radar data source. Although the algorithm guidance has led to an improvement of the National Weather Service (NWS) severe weather warning statistics, it is understood that effective warning decisions can only be made via the integration of information from many sources, including input from multiple remote sensors (multiple radars, mesoscale models, satellite, lightning, etc.). Therefore, these traditional single-radar severe weather algorithms have been updated to take advantage of additional data sources in order to reduce the uncertainty of the measurements and increase the accuracy of the diagnoses of severe weather.

The NSSL Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan 2002) has provided an invaluable development environment to facilitate the development of these new applications. In just the past year (2002), NSSL has converted its suite of single-radar severe weather detection algorithms to operate using multiple radars. NSSL has also developed a suite of new radar diagnostic derivatives, including two-dimensional high-resolution fields of vertically-integrated liquid (VIL), Probability of Severe Hail, Maximum Expected Hail Size, Velocity-Derived Rotation, and Velocity-Derived Divergence. Time-integrated fields of some of the above have also been developed, including hail swath information (maximum size and hail damage potential) and velocity-derived rotation tracks.

## 2. Severe Weather Applications

The use of the WDSS-II development environment has facilitated the rapid implementation of several new severe weather forecast guidance tools as well as improvements to legacy severe weather diagnostic applications.

### *2.1 Legacy Severe Storms Analysis Program*

The original or legacy Severe Storms Analysis Program (SSAP) was the NSSL-developed algorithm system that included some of the severe weather algorithms that are now operational within the National Weather Service (NWS) suite of WSR-88D algorithms. The SSAP components that have been integrated into the WSR-88D include the Storm-Cell Identification and Tracking (SCIT) algorithm, the cell-based Hail Detection Algorithm (HDA), and the Tornado Detection Algorithm (TDA). One additional component of the SSAP, the Mesocyclone Detection Algorithm (MDA), is presently being engineered for the WSR-88D and will be fully integrated by the fall of 2003. A fifth SSAP component, the Damaging Downburst Prediction and Detection Algorithm (DDPDA), has not been integrated into the WSR-88D system.

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| NSSL Enhanced Hail Diagnosis Algorithm Output | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CELLID | AZ | RAN | HAIL | POSH | MEHS | S < 1.5 | 1.5 - 2.5 | S ≥ 2.5 | VIL | SHI | MRV | STD | MAX Z | BASE Z |
| 1 | 253 | 90 | 100 % | 50 % | 2. 00 | 30 % | 40 % | 30 % | 50 | 208 | 69 | 126 | 58 | 56 |
| 2 | 241 | 110 | 100 % | 60 % | 1. 75 | 30 % | 50 % | 20 % | 80 | 255 | 26 | 126 | 58 | 56 |
| 3 | 343 | 122 | 100 % | 50 % | 1. 75 | 50 % | 40 % | 10 % | 67 | 210 | UNK | UNK | 60 | 60 |
| 4 | 254 | 94 | 80 % | 20 % | < 1.00 | 80 % | 20 % | 0 % | 44 | 69 | 20 | < 40 | 61 | 61 |
| 5 | 316 | 85 | 90 % | 0 % | < 1.00 | 80 % | 20 % | 0 % | 14 | 36 | 22 | RF | 51 | 51 |

*Figure 1. Table showing output from NSSL's Enhanced Hail Diagnosis Algorithm (EHDA). Rows represent individual SCIT-detected storm cells, and columns show hail attributes per cell. Selected column headers include POSH (probability of severe hail), MEHS (maximum expected hail size in inches), S<1.5 (probability of hail < 1.5" diameter), 1.5-2.5 (probability of hail between 1.5"-2.5" diameter), and S≥2.5 (probability of hail ≥ 2.5" diameter).*

Each of the algorithms, as implemented into the WSR-88D system or within the NSSL SSAP, operates using only single-radar data. In the case of the WSR-88D HDA, some limited thermodynamic information (height of 0ºC and -20ºC levels) from a nearby sounding must be manually input into the algorithm. The NSSL SSAP version of the HDA integrates near-storm environment (NSE) data from the RUC mesoscale model analysis so that the selection of the HDA thermodynamic data is automated and has higher temporal and spatial resolution than synoptic-scale soundings.

### *2.2 Enhanced Hail Diagnosis Algorithm*

NSSL has enhanced the original single-radar cell-based HDA. This improved hail diagnosis uses a sophisticated and more-accurate Neural Network that integrates the traditional reflectivity radar information with velocity radar information (for rotation and storm-top divergence) as well as NSE data from a mesoscale model (Marzban and Witt 2001). Additional outputs include hail size conditional probabilities for three categories: <1.5", 1.5" – 2.5", and ≥2.5". The output data are made available for icons, tables, and trends. An example of an EHDA table is shown in Fig. 1.

### *2.3 Multiple Radar SSAP*

The Multiple-Radar Severe Storms Analysis Program (MR-SSAP; Stumpf *et al* 2002) extends the concepts of the legacy SSAP into the multiple-radar, multiple-sensor realm. The disadvantages of single-radar data are that 1) products are generated only once at the end of a 5- or 6-minute volume scan (already 5-6 minutes older than latest lowest-elevation radar data), 2) there is poor sampling at near ranges (cone-of-silence) and far ranges (radar horizon and beam broadening), and 3) all products are keyed to individual radar volume scans and radar domains (azimuth, range, elevation).

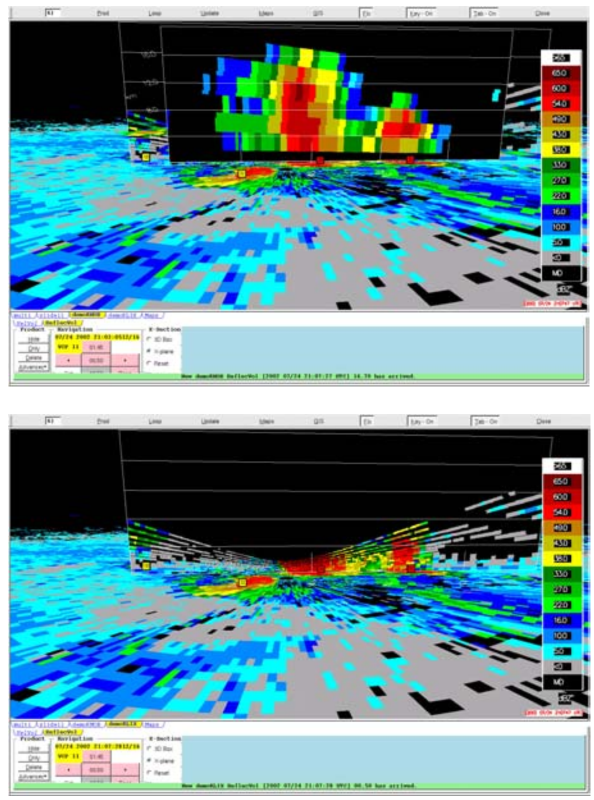

*Figure 2. Vertical cross sections of WSR-88D reflectivity data. Jackson MS (top) data are used to fill in cone-of-silence data void from Slidell LA WSR-88D (bottom). View is from the south of the Slidell radar.*

We have adapted the concepts of the single-radar SSAP to use information from multiple radars. Adjacent radars can be used to fill in cones-of silence (Fig. 2) or areas of beam blockage. Multiple radar data are mosaicked into virtual volume scans, with the latest

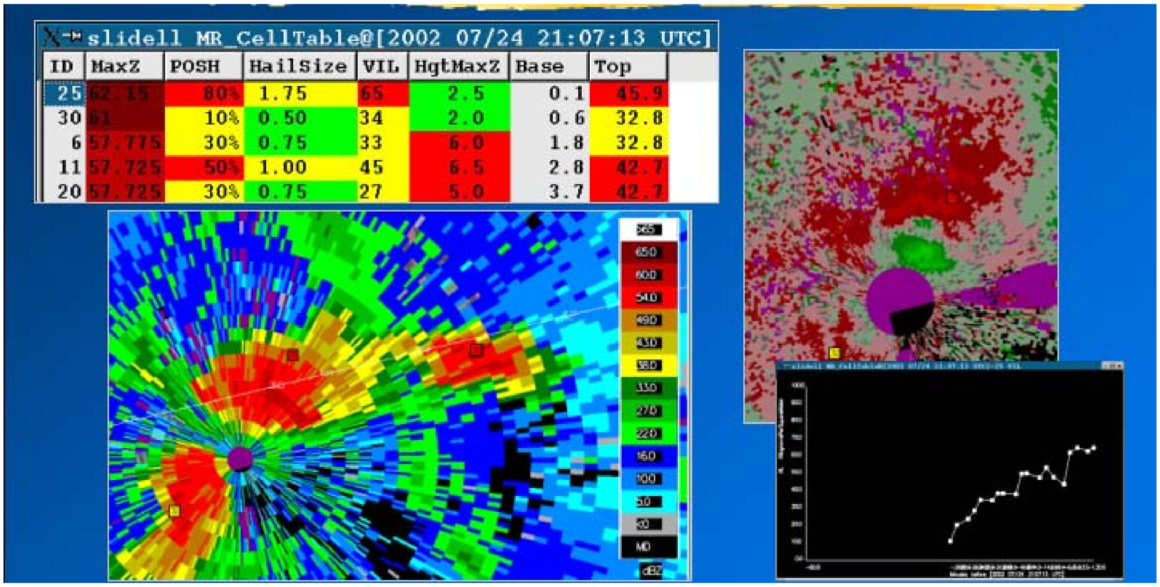


*Figure 3. MR-SCIT and MR-HDA output for same storm in Fig. 2. Storm Cells are represented by numbered red or yellow squares overlaid on radar data (lower left and upper right). Storm cell and hail diagnostic information is presented in the table in the upper left. 60-second rapidly updating trend of cell-based VIL is shown at the lower right.*

elevation scan of data replacing the one from a previous volume scan. This method gives a complete volume scan at any point in time. We are able to generate output products in rapidly updating fashion as quickly as one individual radar elevation scan is included in the virtual volume (10-20 seconds). Presently, we run the updates at 60-second intervals for better warning management. The rapidly updating virtual volume can also run with single radar mode if coverage and outages dictate. The virtual volumes are designed to be VCP-independent, and can be integrated with other "gap-filling" radar platforms, including FAA and commercial radars. Products are keyed to a four-dimensional earth-relative coordinate system (latitude, longitude, elevation, time).

### *2.4 Multiple Radar SCIT and HDA*

Reflectivity information from multiple radars is used to detect and diagnose storm cells. Virtual volumes of radar data containing the latest information from each radar for the previous 5 minutes are combined to produce vertical cores representing storm cells. The multi-radar reflectivity data used to construct the storm cells is diagnosed to give traditional cell-based attributes such as vertically integrated liquid (VIL). Cell-based HDA information (POSH, hail size) is also diagnosed using the

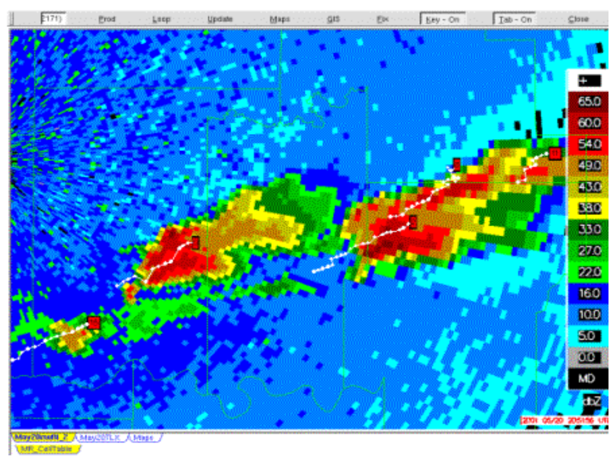


*Figure 4. Oklahoma City OK WSR-88D data and current MR-SCIT storm locations (red numbered square icons) and 60-second past positions (white dots and lines). Note that current storm locations are already downstream of latest reflectivity data from Oklahoma City WSR-88D, owing to new information from Tulsa OK and Fort Smith AR WSR-88D data (not shown).*

combined multiple radar data, as well as NSE data from mesoscale models (Fig. 3). The cell-based storm and hail diagnoses are done rapidly at 1-minute intervals. Storm cells are also tracked in time (60-second intervals), attribute data are available for 60-second interval trend

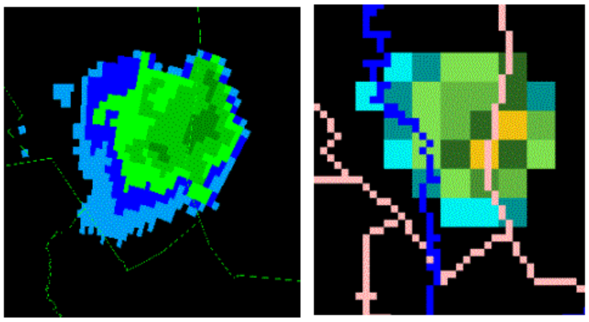

*Figure 5. High-resolution, two-dimensional Vertically Integrated Liquid (VIL) on left, and low-resolution 2km gridded WSR-88D VIL on right.*

information, and 30-minute forecast positions are made (Fig. 4).

### 2.5 High resolution maximum vertical-column reflectivity (MVR), Vertically Integrated Liquid maps

Presently, WSR-88D two-dimensional maps of maximum vertical-column reflectivity (sometimes known as “Composite Reflectivity”) and Vertically-Integrated Liquid (VIL) are presented with poor spatial (2 km Cartesian grids) and poor temporal (5-min updates) resolution (Fig. 5). NSSL has developed high-resolution spatial (same as polar radar data) and temporal (using virtual volumes with 10-20 second updates) versions of these popular products. Work is underway to develop multiple-radar mosaics of these products.

### 2.6 Two-dimensional Probability of Severe Hail, Hail Size, and Hail Track Maps

The techniques used to derive popular WSR-88D cell-based hail products from the HDA have been incorporated into high-resolution two-dimensional products similar to the high-resolution MVR and VIL products. This allows a user to diagnose which portions of storms contain large hail. Hail size data are accumulated over time to provide precise hail swath maps, showing both maximum hail size by location, and hail damage potential (combination of hail size and duration of hail) (Fig. 6). Future work is planned to develop multiple-radar mosaics of these products and to adapt the Enhanced-HDA in a similar manner.

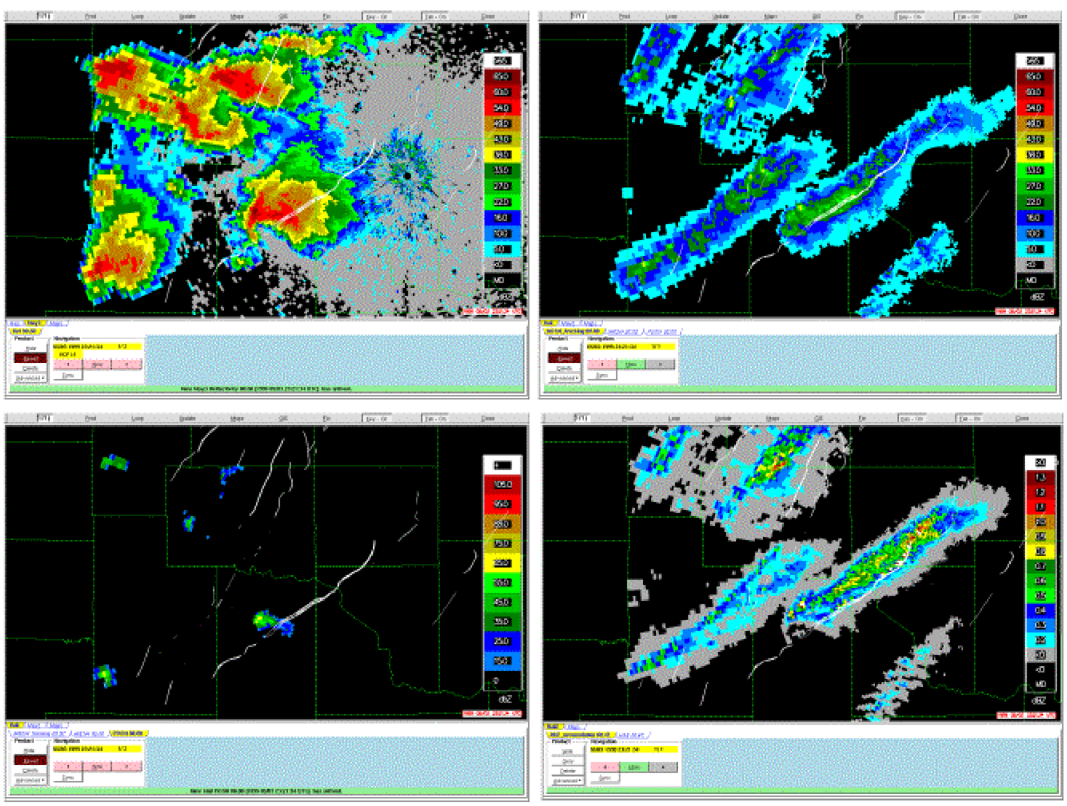

*Figure 6. Oklahoma City OK WSR-88D reflectivity during 3 May 1999 tornado outbreak (upper left); Two-Dimensional Probability of Severe Hail (POSH) field (lower left); Hail size swath field (upper right), Hail Damage Potential Accumulation field (lower right). The thin white contours represent the tornado damage tracks.*

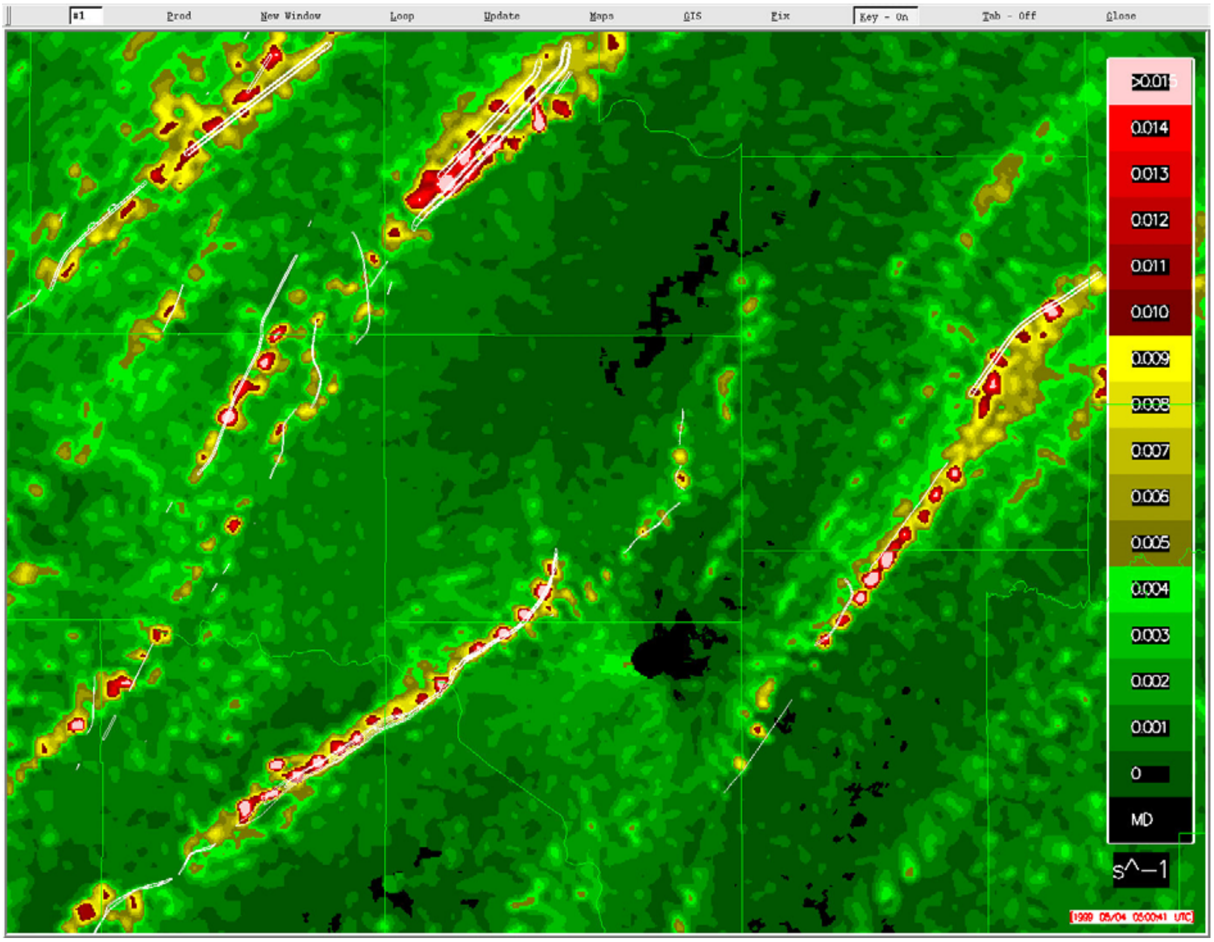


*Figure 7. Eight-hour Accumulated shear (rotation) field for the 3 May 1999 tornado outbreak in Central Oklahoma. Thin white lines are the actual tornado track locations from NWS damage survey.*

### *2.7 Vortex Detection and Diagnosis*

More sophisticated techniques are being developed to accurately detect and diagnose rotation in radar velocity data. Present techniques search for patterns of vertically correlated azimuthal shear in single-Doppler velocity data. Current research has shown that these azimuthal shear techniques do not accurately estimate vortex location, size, and strength as well as techniques employing velocity derivatives of rotation and divergence. Traditional azimuthal shear techniques can also produce false detections along non-rotation signatures. Radial velocity values are a factor of single-radar viewing angles (one component of velocity is measured – that along the radar beam). Velocity derivatives are much less dependent on radar viewing angle, which allows for the combination of two-dimensional rotation fields from multiple radars. Two-dimensional

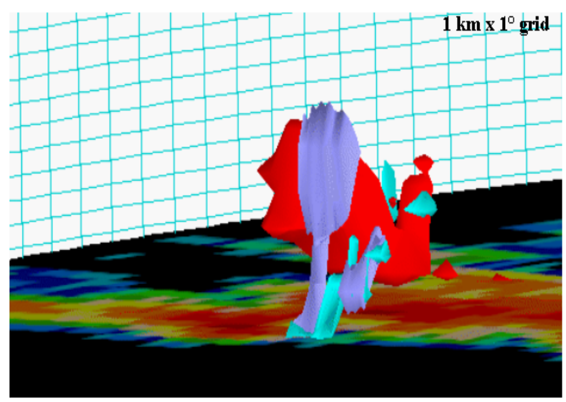


*Figure 8. Three-dimensional image of an isosurface of rotation in a supercell storm. Lavender represents azimuthal shear exceeding $10^{-2}$ $s^{-1}$. Other isosurfaces are 55 dBZ reflectivity (red) and convergence exceeding $10^{-2}$ $s^{-1}$ (aqua).*

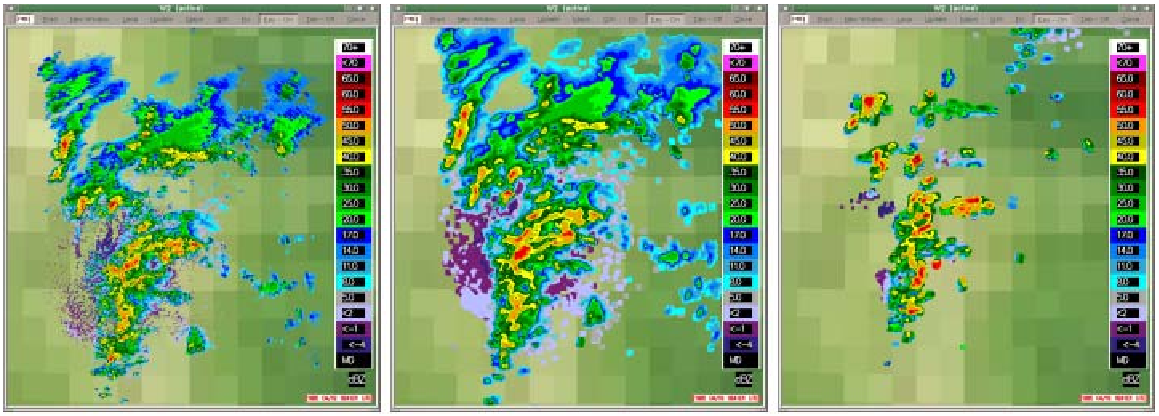

*Figure 9. Current reflectivity field (left), 15 minute forecast (center), 60 minute forecast (right).*

rotation fields from single and multiple radars can also be accumulated over time providing tracks of mesocyclone features (Fig. 7). Three-dimensional rotation fields can be used to depict the vertical "tube" of the mesocyclones (Fig. 8).

### *2.8 Motion Estimation*

NSSL is currently developing a sophisticated technique to forecast the motion, growth, and decay of two-dimensional storm fields (Lakshmanan 2003). This is not a cell tracker, but rather a forecast of 2D radar or satellite fields. Up to 60-minute forecasts of these two-dimensional products can be produced (Fig. 9). The result also includes a high-resolution motion field that can be used to advect any two-dimensional product, such as hail, rotation, or lightning fields to provide up to 60-minute forecasts of these phenomena.

### *2.9 Near-Storm Environment Algorithm*

NSSL has developed an algorithm that analyzes mesoscale model output and derives a large number of sounding parameters (e.g., CAPE, helicity). These derived gridded data are used as source input to a number of our current and proposed algorithms.

## 3. Application Development Environment

The Warning Decision Support System - Integrated Information (WDSS-II; Hondl 2002, Lakshman 2002) greatly facilitated the development process of the MR-SSAP. The WDSS-II system includes 1) real-time data ingest of data from multiple radars and sensors, 2) detection, diagnosis, and prediction multi-sensor algorithms, 3) an interactive display designed specifically to effectively manage and provide rapid access to the most important information for decision-making (including novel 4D earth-relative base-data visualization techniques), and 4) an infrastructure to support application development, data ingest and distribution, configuration, and extensible output data formats. The Application Programming Interfaces provided within the WDSS-II development environment were utilized to provide access to time-synchronized multiple WSR-88D data streams (in offline and real-time modes), as well as to output the data in a variety of extensible data formats (NetCDF and XML). The object-oriented structure of the code also facilitated the development of functions that can be reused using other data sources (such as other radars besides WSR-88D, including FAA and commercial "gap-filling" radars). The WDSS-II and MR-SSAP are designed using economical Linux systems.

## 4. Acknowledgements

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