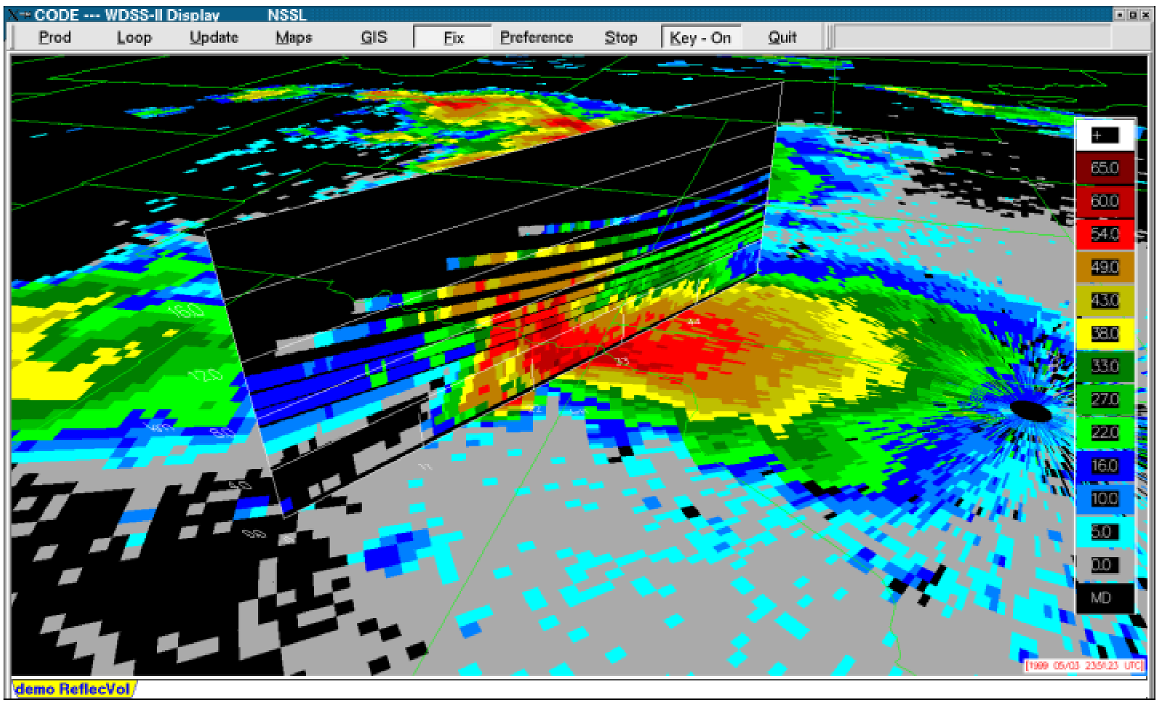
NATIONAL SEVERE STORMS LABORATORY

WICHITA KANSAS NWSFO

WARNING DECISION SUPPORT SYSTEM – INTEGRATED INFORMATION (WDSSII) PROOF-OF-CONCEPT TEST

<u>OPERATIONS PLAN</u>



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PREFACE

Welcome! Consider yourself part of a unique team of National Severe Storms Laboratory (NSSL) and Wichita Kansas National Weather Service Forecast Office (NWSFO) meteorologists, working together to test new and experimental severe weather warning applications. This operations plan is written for the team as a whole. In here you will find information about the various new applications that we are testing during the 2003 spring convective season at Wichita. We will also describe the new NSSL Warning Decision Support System – Integrated Information (WDSSII), including the data ingest, data integration, new severe weather applications, and the innovative 4D display. The overall purpose of the WDSSII is to test new multi-sensor severe weather application and 4D display concepts before they are eventually implemented into NWS operational systems such as AWIPS.

Remember that severe weather warning decision-making is a multi-dimensional process. Data from many sources, including 4D weather observations from multiple sensors, spotter reports, algorithm output, near-storm environment information, and basic knowledge of severe weather are all integrated in the decision-making process. Scientists at NSSL realize that since effective warning decision-making integrates multiple-source data, severe warning applications should also integrate data from many sensors and sources. Hence, we are testing the next generation of multiple-source applications. Also, the atmosphere is a four-dimensional process. The weather sensor data we use for warning decision-making is also four-dimensional (3D space and time). It only makes sense that these data are viewed in their native formats, with the highest resolution available and in all four dimensions, and this is possible with the WDSSII display.

The WDSSII system is designed to merge multiple-source data (multiple-radars, environmental data, etc) into a common application and display platform. The Wichita WDSSII system integrates the data from five WSR-88Ds (KICT, KDDC, KVNX, KINX, KTWX) and runs a variety of new multiple-radar applications on the multiple-radar data feed. WDSSII algorithm represents the **next generation** of WSR-88D single-radar algorithms. The WDSSII also allows the user to access all the data sources and overlays them onto a single image (multiple panels are also available). By integrating data from multiple-radars and multiple-sensors, we decrease the uncertainty of the detections and thus increase the accuracy of the detections and predictions. This will hopefully lead to better guidance, and an increase in POD and reduction of FAR. All data are plotted in 4D earth-centric and time-synchronized coordinates and are the very latest available (no more waiting till the end of volume scans for products). The applications also produce output at rapid intervals (30-60 seconds) instead of the usual 5-6 minute wait between volume scans. Earlier guidance means warnings can be issued sooner, thus increasing warning lead-time. More detailed guidance (e.g., exact location in a storm of hail of particular sizes) also leads to improved service to the public. And most of all, remember that the algorithm and application output serves as **guidance**, and as a **"safety net"** to alert the user of important weather, and **<u>are not intended to replace the human in the decision-making process</u>**. The NWS user makes the warning decision based on all the available information, and the WDSSII provides easy access to all of this information.

The WDSSII "points" the user to the important storms, and allows the user to slice-and-dice and "fly around" the 4D data to gain the best perspective of the situation.

NSSL also plans to rapidly-prototype new applications and concepts into the WDSSII system during the test. Certain applications are currently under development and improvement, and when we feel that something new is ready for testing, we will deploy the new application at Wichita during the test. Also, certain new improvements suggested by NWSFO users can be quickly implemented during the test to gain immediate feedback. And since the WDSSII is also a multiple-sensor application development system, it offers the chance for savvy NWS staff to develop and test their local applications as well.

It is NSSL's desire to get feedback from the Wichita NWSFO meteorologists on the new multiple radar products and the 4D display system. Therefore, during the Spring 2003 severe weather season, NSSL will staff at least one meteorologist during most severe weather episodes at the NWSFO during a three-month period (April-June). The NSSL meteorologist will observe the NWSFO use of the WDSSII system. They will also observe the NWS warning environment, so that NSSL can better understand your operational requirements. NSSL is looking for feedback from the NWS – what is better about the new system, and how to make the system even better. Surveys will be administered to the NWSFO staff that uses the WDSSII. Short surveys will be given at the end of shifts, and a longer questionnaire will be given after the spring. Remember, input from the Wichita meteorologists is **vital** to the improvement of the NWS warning process, which ultimately saves public lives and property. The NWS feedback on this test is most important for future funding for multi-sensor warning application development for the NWS and eventual implementation of new application and display concepts into AWIPS and other operational systems. NSSL desires constructive criticism; let's work together as friends and as a team.

EXECUTIVE SUMMARY

The National Severe Storms Laboratory (NSSL) has conducted proof-of-concept tests of the NSSL Warning Decision Support System (WDSS) at several National Weather Service Forecast Offices (NWSFO). The legacy WDSS included enhanced NSSL single-Doppler-radar based algorithms, imaging techniques, and innovative algorithm product display capabilities. The legacy single-radar NSSL algorithms include the Storm Cell Identification and Tracking (SCIT) algorithm, Hail Detection Algorithm (HDA), Tornado Detection Algorithm (TDA), Mesocyclone Detection Algorithm (MDA), and the Damaging Downburst Prediction and Detection Algorithm (DDPDA). The original WDSS serves as the vehicle for testing new technology in the 1990s. The first three algorithms (SCIT, HDA, and TDA) are officially part of the WSR-88D system. A fourth algorithm (MDA) will be added by the spring of 2004. And new display techniques from the original WDSS have already been incorporated into the AWIPS system.

The NSSL Warning Decision Support System – Integrated Information (WDSSII) is the next-generation of algorithm and display technology for warning decision making. It is an experimental system designed to test new concepts for both automated guidance algorithms and display techniques. The WDSSII primary improvements are multiple-sensor integration for new algorithms and a novel four-dimensional display system. Wichita Kansas is the second NWS location for a formal proof-of-concept test of the new technology. We hope that this test, and others that follow, will lead to even better improvements to the technology used by the NWS to issue severe weather warnings.

The primary objectives of the WDSSII proof-of-concept tests are as follows:

- To **evaluate the accuracy and the operational utility of** NSSL's new enhanced severe and hazardous weather prediction **multi-sensor algorithms** during real-time operational warning situations.

    - Proof-of-concept tests present opportunities to test the experimental algorithms during NWS severe-weather warning operational situations. This test will identify any special area of focus for additional algorithm development prior to their inclusion into NWS systems.
    - The Central Plains U.S. climatology should allow us to determine if our algorithms are region-independent. Long-term robustness testing of the algorithms is also important, and achieved by running the algorithms continuously for long-periods under varied environmental conditions.
    - The algorithms will each be evaluated qualitatively via feedback questionnaires from the NWS personnel. NSSL staff can assist the NWS staff in collecting real-time verification data and conducting post-storm damage surveys to enhance the quality and quantity of ground truth.

- To **gain feedback** from operational warning meteorologists on the utility and effectiveness of the new Warning Decision Support System-II concept and its

enhanced algorithm and product displays before consideration of their inclusion in official NWS operational systems (e.g., AWIPS, ORPG).

  - Feedback on the utility of the WDSSII display and needed additions and enhancements will be acquired from the NWS meteorologists via post-shift questionnaires and by observations of real-time operational use by NSSL staff. This feedback is very important to help NSSL determine how the algorithm output will be displayed on NWS operational systems.

- To **provide operational experience to NSSL meteorologists** and developers during real-time warning situations in order **to better understand user requirements**.

  - The interaction between NSSL scientists and operational meteorologists will provide a synergy that will lead to improvements in future products. The operational meteorologists will also get first-hand experience with next-generation algorithms and product display concepts.

- To **foster collaboration** between NSSL scientists and operational meteorologists.

  - The NWS is NSSL's primary customer. We want to work with you to understand your requirements and improve warning accuracy and services. This will also allow for continued scientific collaboration on application development, and on informal and formal publications.

I. WDSSII COMPONENTS

The Warning Decision Support System – Integrated Information (WDSSII) has four main components:

1. Real-time Data Integration

- Integrates radar data with other observing systems for total view of the weather situation. Only multiple WSR-88D and RUC20 output will initially be available for Wichita (other sources may be added later):

    - Multiple radar data streams (WSR-88D, TDWR, etc.)
    - Mesoscale Model output (e.g., RUC20)
    - Surface observations (including mesonets)
    - Lightning
    - Satellite
    - Weather watches & warnings

- Converts all data to a common coordinate system

    - Earth- and time-centric, 4-Dimensional coordinates
    - All data sources time-synchronized

2. Experimental Multi-Sensor Algorithms

- Evaluate/test new algorithms using latest available techniques for the greatest utilization of the observational data for both detection & prediction

    - Algorithm technologies above and beyond what is available in the current WSR-88D system
    - Allows development to feedback into official NWS operational systems such as ORPG and AWIPS systems
    - Ability to quickly prototype and test applications

- Integrates multi-source information

    - Multiple radars, sensors, other algorithm information

3. Interactive 4D Display (see also Appendix B – w2 Display User Guide)

- Innovative display capabilities that highlight severe weather signatures and provide data analysis tools

    - Integrate other data sources
    - Algorithm output (with interactive filters)
    - Mosaic/composite images
    - Trends and time-height trends
    - Tables (user configurable & sort capabilities)

- Interactive 3D display tools

    - Dynamic cross sections and CAPPIs of highest-resolution radar data
    - Virtual Volume displays

        - Update 3D volume as pieces become available
        - Easy navigation of data by the operator

4. Infrastructure

- A tool for operational testing and research & development (R&D)

- Economical Linux-based system

- Expandable and flexible design

- Applications/Algorithms

- New 4D display software

    - For testing of new algorithms & display concepts
    - Can customize output on the fly

- Development environment

    - Common APIs for data access
    - Open, standard, and extensible data formats (NetCDF, XML, shapefiles)
    - Object-oriented design with a library of functions and classes
    - Common software development tools (CVS, Doxygen)
    - Distributed computing

II. MULTIPLE-SENSOR SEVERE WEATHER APPLICATIONS

The National Severe Storms Laboratory (NSSL) has played the primary role in the development and evaluation of U. S. National Weather Service (NWS) severe weather applications for the Weather Surveillance Radar – 1988 Doppler (WSR-88D). The development process at NSSL begins with basic and applied research including field experiments, theoretical studies, and case studies designed to better understand storms and relate weather to remotely sensed signatures. This research leads to the development of applications, including computer algorithms employing sophisticated image processing and artificial intelligence, and innovative display systems used to enhance the research and development process. Evaluations are conducted using archived case studies as well as real-time proof-of-concept tests at NWS forecast offices (NWSFO) during actual severe weather warning operations. Feedback from the evaluations leads to further research and refinement of applications, and ultimate operational applications for users. The new concepts continue to be tested to determine whether they will be included in future operational systems that help guide and manage the severe weather warning decision-making process.

NSSL developed many of the primary severe weather algorithms for the WSR-88D, 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 NSSL-developed algorithm guidance has led to an improvement of the 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 detection, diagnosis, and prediction of severe weather.

The NSSL Warning Decision Support System – Integrated Information (WDSS-II; Lakshman 2002) has provided an invaluable application programmer interface (API) to facilitate the development of many new multiple-sensor severe weather applications for severe weather warning services. In just the past year (2002), NSSL has developed a variety of new algorithms and major upgrades to existing algorithms. NSSL has converted its suite of single-radar severe weather detection algorithms to operate using multiple radars. These include multiple-radar versions of the Storm Cell Identification and Tracking (SCIT) algorithm (Johnson, et al. 1998), and the Hail Detection Algorithm (HDA; Witt et al. 1998). Under development is a multiple-radar replacement for both the Mesocyclone Detection Algorithm (MDA; Stumpf et al. 1998) and the Tornado Detection Algorithm (TDA; Mitchell et al. 1998) known as the Vortex Detection and Diagnosis Algorithm (VDDA). NSSL has also developed a host of new radar diagnostic derivatives, including high-resolution gridded fields of vertically integrated liquid (VIL), Probability of Severe Hail, Maximum Expected Hail Size, Velocity-Derived Rotation, and Velocity-Derived Divergence. Time-integrated gridded 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.

LEGACY SEVERE STORMS ANALYSIS PROGRAM (SSAP)

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; sans tracking). 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; Smith et al. 2002), has yet to be integrated into the WSR-88D system. The version of the TDA in the NSSL SSAP also includes tracking and trend information, which were omitted during WSR-88D integration.

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 Rapid Update Cycle (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.

Testing of the SSAP was done in offline mode with archived WSR-88D Level II data, or in real-time. Real-time testing was conducted using NSSL's Warning Decision Support System (WDSS; Eilts et al. 1996) at a variety of United States National Weather Service (NWS) Forecast Offices (NWSFO) nationwide since 1993. Both of these legacy systems, the SSAP and the WDSS, were developed as single-radar software systems. All algorithm and radar products were keyed to the individual volume scans and individual radars.

Even with the limitations of single-source algorithms and systems, the WDSS proved valuable for warning improvements. Many of the then-experimental NSSL severe weather algorithms were integrated into the present-day WSR-88D system. This concept continues to be used to test the improvements and additions to the NSSL severe weather analysis applications to be discussed in the following sections.

For Wichita, most of the legacy SSAP algorithms are already available on the WSR-88D/AWIPS system, and will not be available on the WDSSII. The WDSSII will only include our newest multiple-sensor severe weather applications.

ENHANCED HAIL DIAGNOSIS ALGORITHM (EHDA)

NOTE: The EHDA is not expected to be available during the Spring 2003 Proof-of-Concept Test. It is presented here to complete the description of NSSL's latest suite of severe weather applications.

NSSL has enhanced the original single-radar cell-based HDA, known as the Enhanced Hail Diagnosis Algorithm (EHDA; Marzban and Witt 2001). 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. Additional outputs include hail size conditional probabilities for three categories: <4 cm, 4 – 6 cm, and ≥6 cm. The output data are made available for icons, tables, and trends. An example of an EHDA table is shown in Fig. 1.

NSSL Hail Algorithm Output for Volume 275

CELLID	AZ	RAN	HAIL	SVRH	SIZE	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" (4 cm) diameter], 1.5-2.5 [probability of hail between 1.5"-2.5" (4 – 6 cm) diameter], and S≥2.5 [probability of hail ≥ 2.5" (6 cm) diameter].

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 present architecture of each algorithm is to detect two-dimensional (2D) features on radar elevation scans. At the end of each complete radar volume scan, the 2D features are vertically associated to create 3D detection products (e.g., storm cells, mesocyclones, TVSs). These 3D detections are also time-associated with 3D detections from a previous volume scan to produce tracks and trends. This method leads to a variety of disadvantages. First, algorithm products are only generated at the end of a volume scan, which is typically 5-6 minutes after the first elevation scan of the volume scan is collected. This has led to warning meteorologists placing less weight on the algorithm products for warning guidance and more weight on analysis of the more-timely radar data alone without the additional guidance. Second, storm and tornado evolution can typically be very rapid, and 5- or 6-minute algorithm update rates may be inadequate. Third, storms can be poorly sampled at very near ranges to the radar (cone-of-silence) and at far ranges (radar horizon, lower sampling resolution).

An early attempt at a multiple-radar SSAP compared the algorithm detections from the various single-radar sources and determined the "best" radar to use as the one sensing the storm or mesocyclone/TVS with the strongest intensity. This method, called the "County Warning Area (CWA) Table", did not take advantage of combined information from multiple radars, and thus issues like poor sampling still plagued the system. It also did not synchronize for the time difference between the multiple radar scans through similar features.

The MR-SSAP instead *combines* the two-dimensional information from multiple radars and uses these data sets to produce 3D detections. This will allow for a more complete vertical sampling of storms and mesocyclones/TVSs where vertical sampling resolution is degraded. Signatures are now better sampled where adjacent radars are adding data to poorly sampled regions such as cones-of-silence (Fig. 2). Multiple radar data are mosaicked into "virtual volume" scans (Lynn and Lakshman, 2002), with the latest elevation scan of data replacing the one from a previous volume scan. This method gives a complete volume scan at any point in time. Vertical and time association is then performed at regular intervals with the last several minutes of 2D features within a "virtual volume" enabling rapid updating of algorithm output and time-synchronization of the multiple-radar data. Output products can be generated as soon as a new radar elevation scan is included in the virtual volume (10-20 seconds). Presently, the NSSL system runs 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).

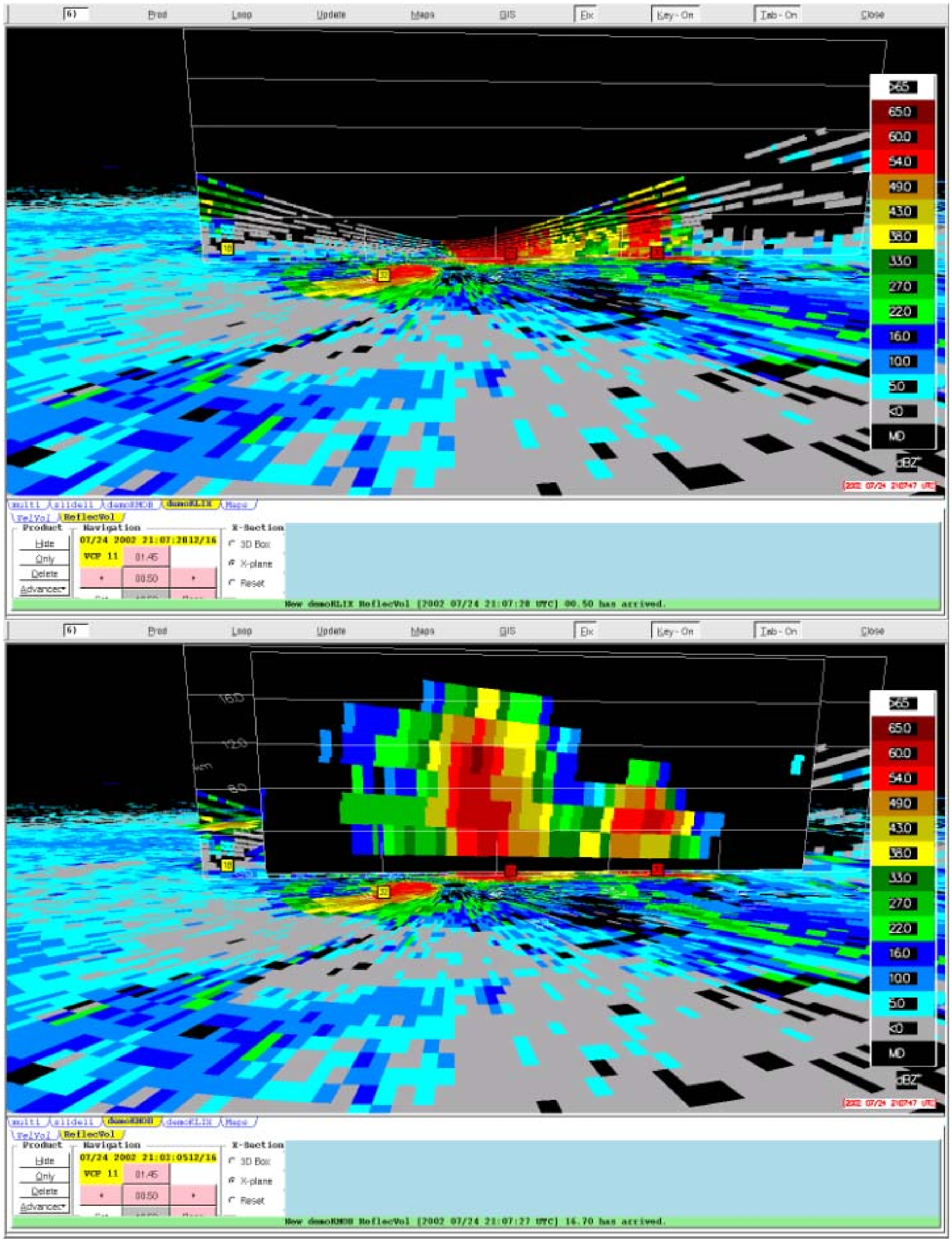


Figure 2. WDSSII image of WSR-88D Slidell, Louisiana, reflectivity data with horizontal and vertical planes as viewed in a three-dimensional "airplane viewpoint" from south of the storm (top). WSR-88D Slidell, Louisiana, horizontal and WSR-88D Mobile, Alabama, vertical reflectivity planes of same data from same 3D viewpoint (bottom). Note that data from Mobile radar are used to fill the Slidell data-void cone-of-silence region. Multiple Radar-SCIT icons are represented by numbered red or yellow squares overlaid on radar data.

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 vertical association technique clusters 2D features from each of the radars within the 5 minute-window into 3D storm features (Fig. 3). Time-to-space conversion is used to account for storm motion for the older 2D features. The vertical association technique is repeated every 60 seconds using all 2D features that are less than 5 minutes old. The multi-radar reflectivity data from the 2D features used to construct the 3D storm cell detections are 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 combined multiple radar data, as well as NSE data from mesoscale models (Fig. 4). The cell-based storm and hail diagnoses are executed rapidly at 1-minute intervals. Storm cells are also tracked in time (60-second intervals), attribute data are available for 60-second interval trend information, and 30-minute forecast positions are made (Fig. 5).

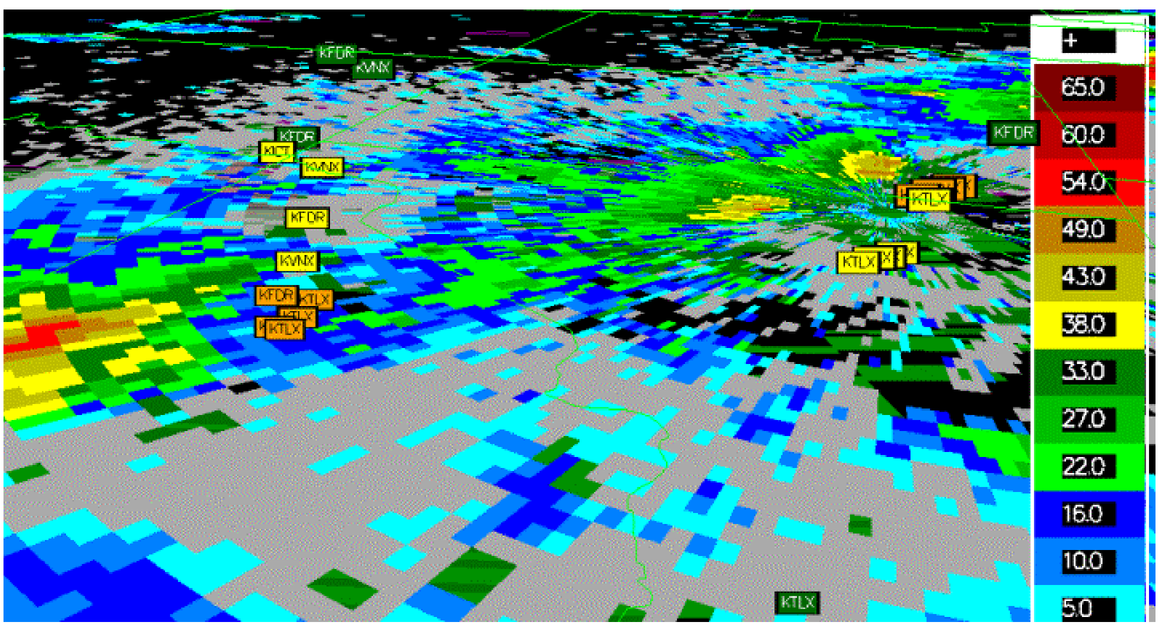
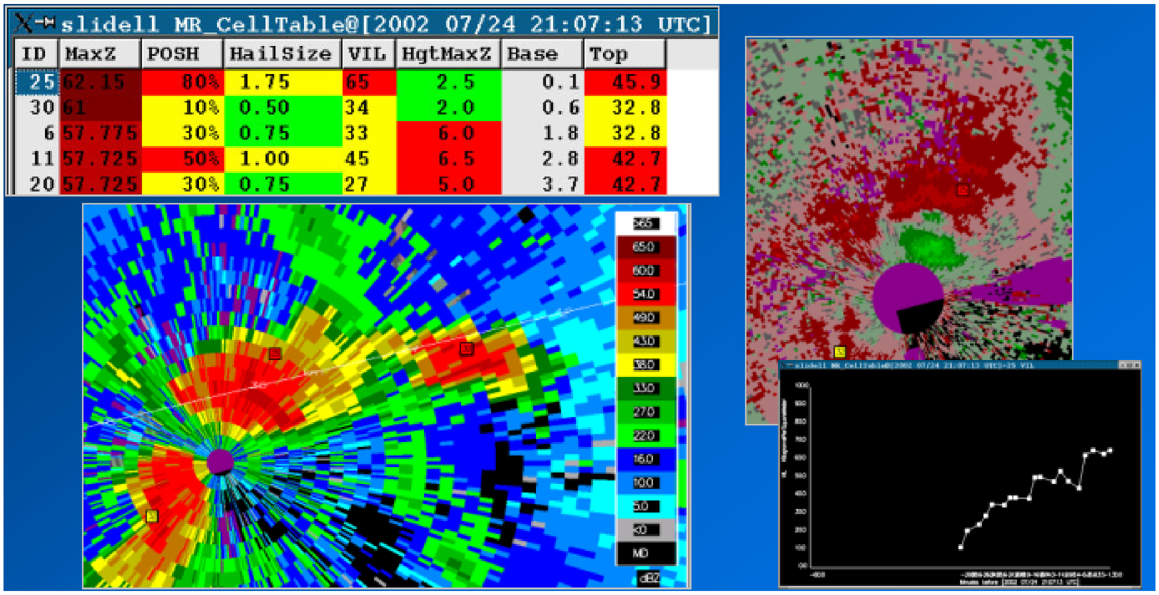


Figure 3. WDSSII image of WSR-88D Oklahoma City, Oklahoma, 0.5° reflectivity data as viewed from an "airplane" angle from the south of the radar, looking down and northwest. Radar location is in the upper right of the image. Overlaid are centroid locations of Multiple Radar-SCIT 2D features, with the 4-letter radar identifier from the originating radar indicated. Icons are color-coded by maximum reflectivity. Note clustering of 2D features to the southwest of the radar. This represents a Multiple Radar-SCIT storm cell comprised of 2D features from multiple radars.



slidell MR_CellTable@[2002 07/24 21:07:13 UTC]

ID	MaxZ	POSH	HailSize	VIL	HgtMaxZ	Base	Top
25	62.15	80%	1.75	65	2.5	0.1	45.9
30	61	10%	0.50	34	2.0	0.6	32.8
6	57.775	30%	0.75	33	6.0	1.8	32.8
11	57.725	50%	1.00	45	6.5	2.8	42.7
20	57.725	30%	0.75	27	5.0	3.7	42.7

Figure 4. Multiple Radar-SCIT and Multiple Radar-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 Multiple Radar-SCIT cell-based VIL is shown at the lower right.

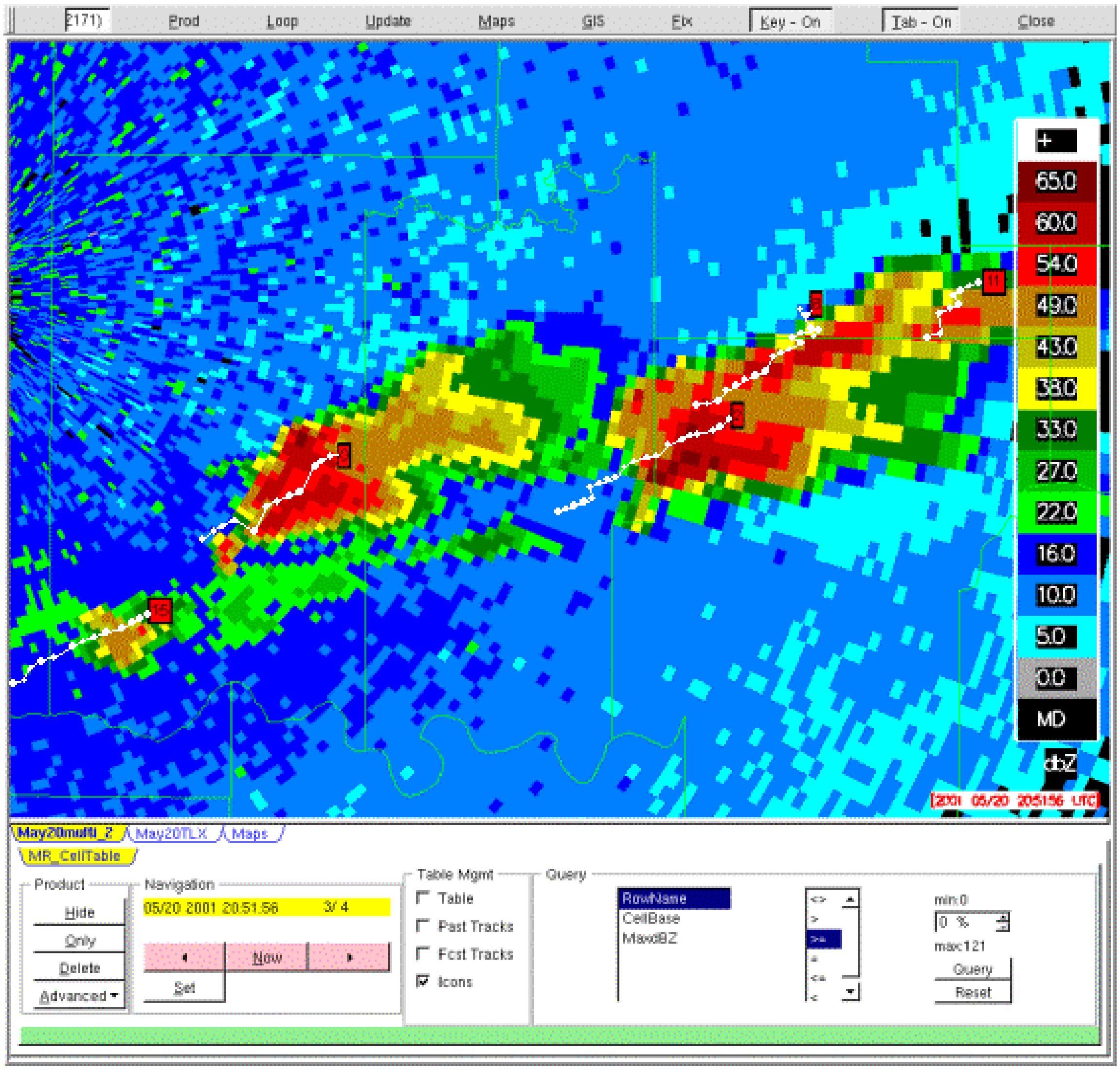


Figure 5. Oklahoma City, Oklahoma, WSR-88D data and current Multiple Radar-SCIT storm locations (red numbered square icons) and 60-second past positions (white dots and lines). Note that current storm locations are already downstream of latest reflectivity data from Oklahoma City WSR-88D, owing to new information from Tulsa, Oklahoma, and Fort Smith, Arkansas, WSR-88D data (not shown).

HIGH RESOLUTION MAXIMUM VERTICAL-COLUMN REFLECTIVITY (MVR), VERTICALLY INTEGRATED LIQUID MAPS

Presently, WSR-88D gridded 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. 6). 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. Multiple-radar mosaics of these products have also been developed, with high spatial resolution (roughly 1x1 km) and high temporal resolution (using virtual volumes with 10-20 second updates) (Fig.7).

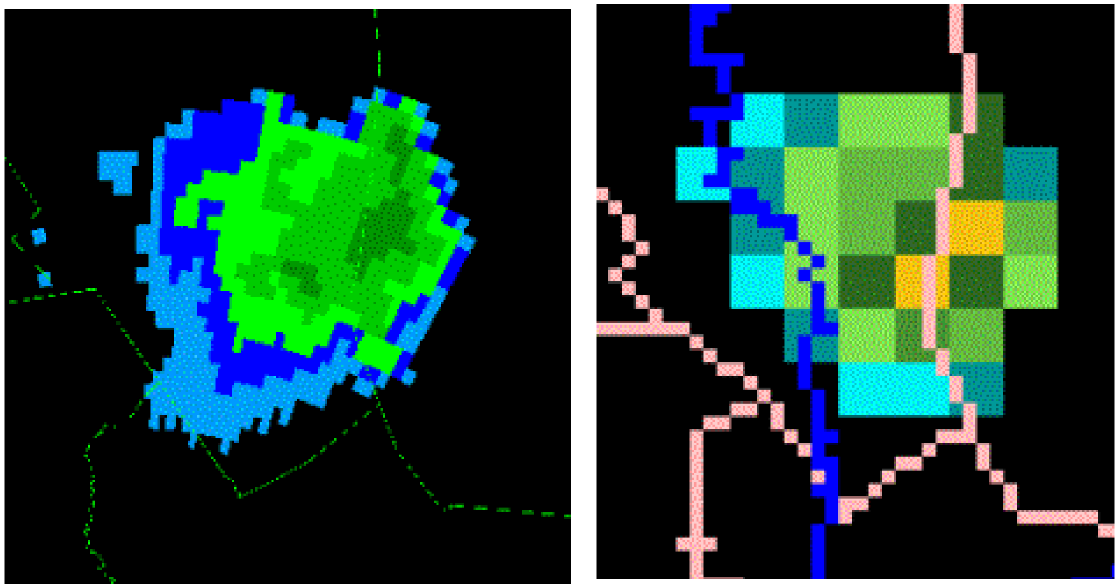


Figure 6. High-resolution polar gridded Vertically Integrated Liquid (VIL) on left (1km by 1º, and low-resolution Cartesian gridded WSR-88D VIL on right (2km by 2km).

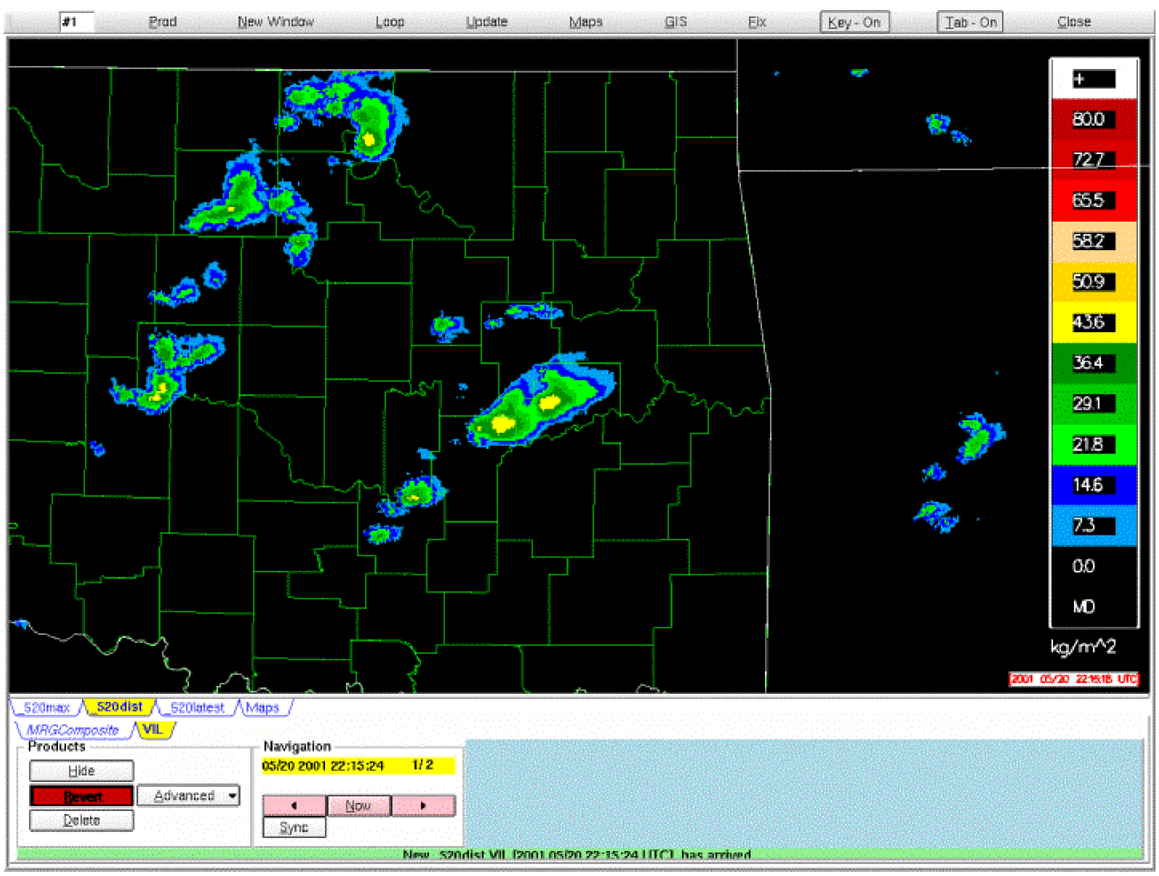


Figure 7. Multiple-radar high-resolution gridded Vertically Integrated Liquid (VIL) (roughly 1 by 1 km). Data from three radars supplied the grid.

GRIDDED 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 gridded 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. 8). Multiple-radar mosaics of these products have also been developed, with high spatial resolution (roughly 1x1 km) and high temporal resolution (using virtual volumes with 10-20 second updates) (Fig.9). Future work is planned to adapt the Enhanced-HDA in a similar manner.

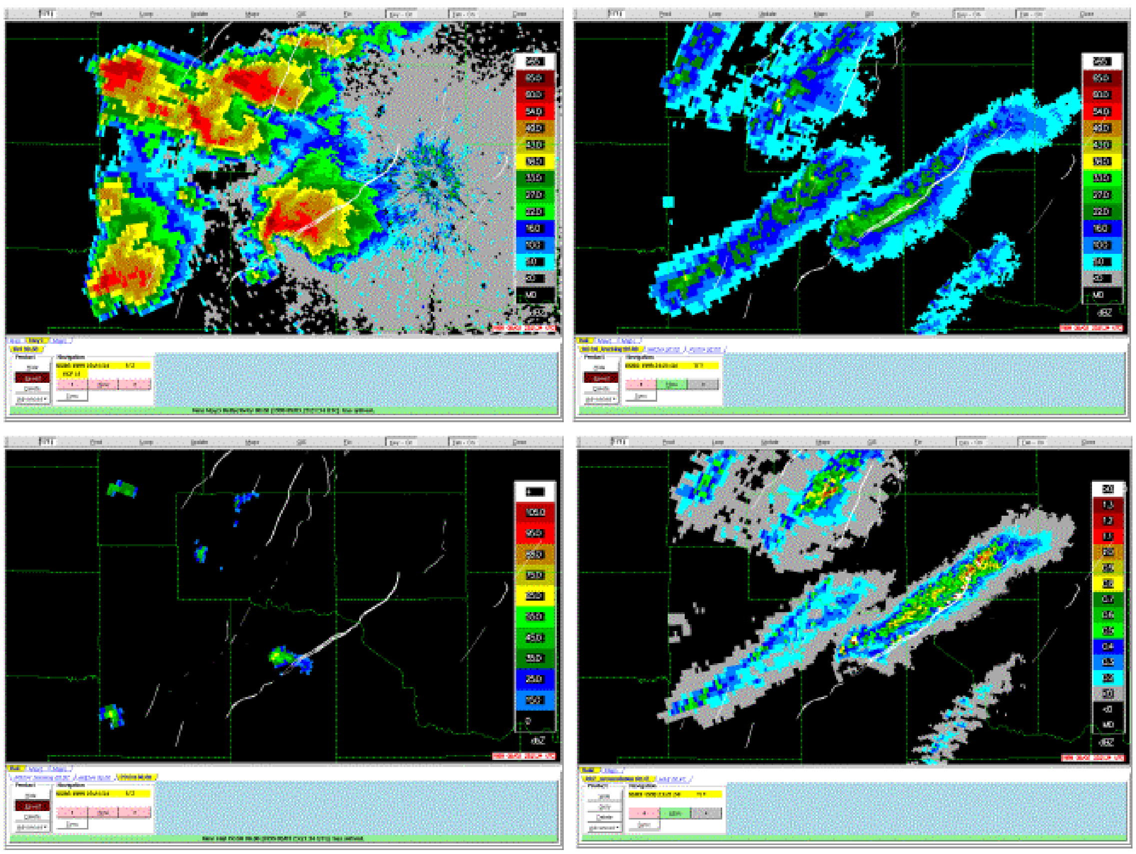


Figure 8. Oklahoma City, Oklahoma, WSR-88D reflectivity during 3 May 1999 tornado outbreak (upper left); High-resolution Gridded Probability of Severe Hail (POSH) field (lower left); Hail size swath field (upper right), Hail Damage Potential Accumulation field (lower right). Overlaid thin white lines are the tornado track locations from NWS damage survey.

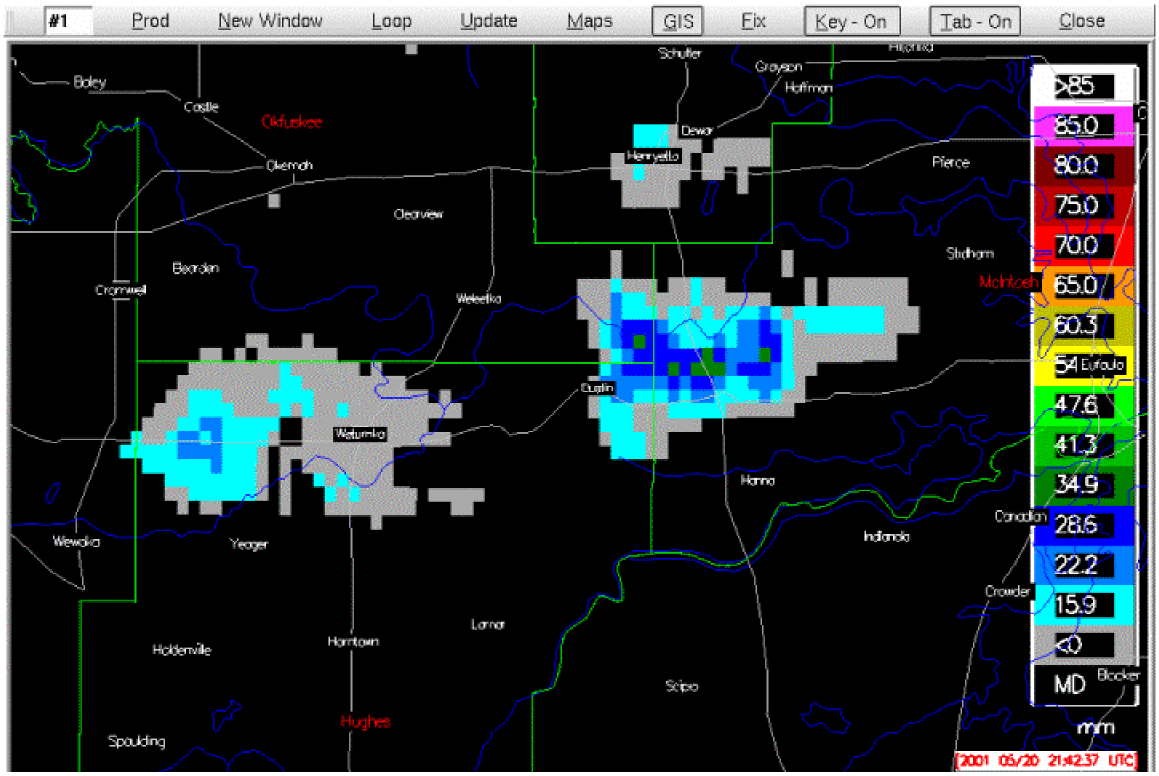


Figure 9. Multiple-radar high-resolution gridded Maximum Expected Hail Size (MESH)(roughly 1 by 1 km). Data from three radars supplied the grid.

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 (Mitchell et al. 1998; Stumpf et al. 1998). Current research has shown that these azimuthal shear techniques are worse at estimating vortex location, size, and strength than techniques that employ 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). Using a Linear Least Squares Derivative (LLSD) technique described by Elmore et al. (1994), derivatives for rotation and divergence are produced in gridded form. These velocity derivatives are much less dependent on radar viewing angle, which allows for the combination of gridded rotation fields from multiple radars. Gridded rotation fields from single and multiple radars can also be accumulated over time providing tracks of mesocyclone features (Fig. 10). Initial multiple-radar versions of these products have been developed, and will be used as the basis for a new Vortex Detection and Diagnosis Algorithm (VDDA) to replace the MDA and TDA.

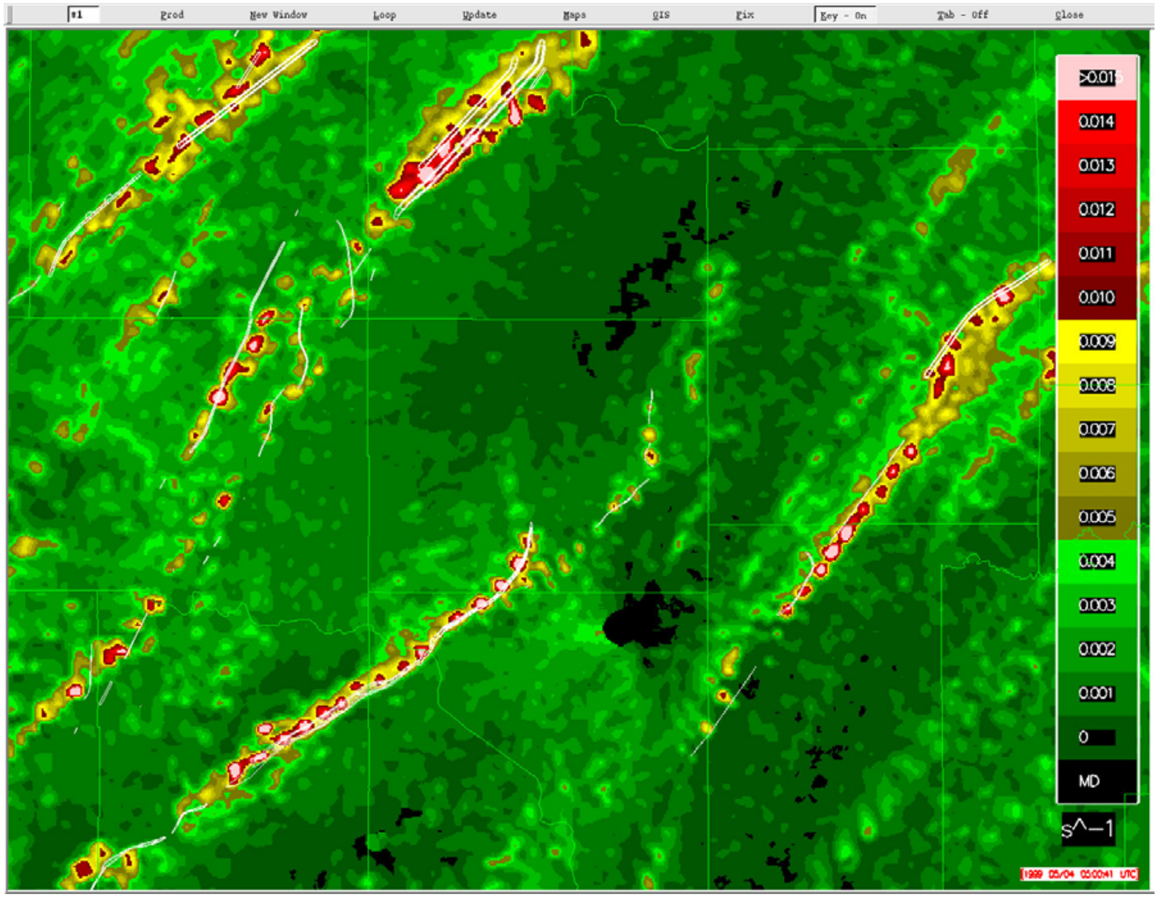


Figure 10. Eight-hour gridded accumulated shear (LLSD-rotation) field for the 3 May 1999 tornado outbreak in Central Oklahoma. Overlaid thin white lines are the tornado track locations from NWS damage survey.

NEAR-STORM ENVIRONMENT (NSE) ALGORITHM

NOTE: Only the fields required by the Multiple-Radar storm tracking and hail algorithms will be provided to the WDSSII in Wichita. Other fields will be added (for display purposes only) if time permits.

NSSL has developed an algorithm that analyzes RUC20 mesoscale model output and derives a large number of sounding parameters (e.g., height of the 0ºC and –20ºC levels). These derived gridded data are used as source input to a number of our current and proposed algorithms.

R&D APPLICATION DEVELOPMENT ENVIRONMENT

The Warning Decision Support System - Integrated Information (WDSS-II; Hondl 2002, Lakshman 2002) greatly facilitated the research and development process of the MR-SSAP. The WDSS-II 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 standard output data formats.

The WDSSII has been developed using economical Linux systems and uses an object-oriented design with a library of functions and classes for real-time (or archived) multiple-source data input, manipulation, and output. The WDSSII integrates data from a variety of sources (multiple radars, satellites, mesoscale models, lightning) and converts all the data to a common coordinate system (3D earth-relative and time-synchronized). The object-oriented structure of the code also facilitates 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 computing structure is distributed, and can be threaded across multiple processors depending on the amount of data and number of applications. The system uses open, standard, and extensible output formats (NetCDF for images; XML for graphics, tables, and trends; shapefiles for geo-located graphics) for use in a variety of display technologies (e.g., OpenGL, Java, Web-based), where output data can be customized on the fly.

FUTURE APPLICATION DEVELOPMENT

The Multiple-Radar SSAP and the high-resolution gridded multiple-sensor hail and rotation products represent only the first phase of improvements for the NSSL experimental severe weather applications. NSSL plans to expand the use of input from other sensors into the algorithms (including mesoscale model, lightning, surface, and satellite data) for a full three-dimensional multiple-sensor suite of severe weather applications. An upgrade to our application and display systems will continue to be tested during 2003 at several U.S. NWSFO and international locations. The results of these tests will lead toward eventual improvement of the severe weather applications for warning services and systems worldwide.

III. OPERATIONS

1. Overview

The WDSSII proof-of-concept tests will take place at selected National Weather Service Forecast Offices (NWSFO). **This specific test will be conducted at the Wichita Kansas NWSFO**. The test will be staffed during most severe weather episodes by at least one NSSL meteorologist for **a three (3) month period beginning 1 April 2003** (or until travel funds have been expended). Deployment and installation of hardware and software will take place during the week of 17-21 March 2003. Training will be conducted during the week of 24-28 March 2003. A two- to three-week period following installation will be used as a "shakedown" period. Within one month after the Operations Period ends (30 June 2003), NSSL staff will conduct a survey of the NWSFO staff (see Appendix A). The purpose of this survey will be to assess the overall users' impressions of the performance of the WDSSII multiple-sensor severe weather applications and display system. The logistics of each WDSS test will be overseen by the *Operations Director* (Mr. Greg Stumpf from NSSL).

To meet the objectives of the WDSS proof-of-concept tests, it is essential that NWS personnel use the NSSL WDSSII during the warning operations process. The WDSSII needs to be used in conjunction with the AWIPS system, rather than "in competition" with them. Although there are many enhancements to algorithms and algorithm product displays contained within the WDSSII, the NSSL WDSSII does not provide every function or product that is available on the other systems. NSSL also realizes that the NWSFO staff are much more familiar with the other systems. With time, during each Operations Period for each site, NSSL hopes that the NWSFO staff will become comfortable working with the WDSSII, and that the system will provide a valuable addition to the tools currently being used for warning operations. Eventually, NSSL wishes to see some of these new multiple-sensor applications and display concepts implemented into official NWS operational systems such as AWIPS.

2. Equipment

The equipment used for the WDSSII system consists of two economical Linux-based PCs (using the RedHat Version 7.3 OS). The first machine (w2ict1) is the display machine, which resides in the operations area of the NWSFO, adjacent to the AWIPS machines. This machine uses a single 2.2 GHz microprocessor, 2 GB RAM, an 80 GB hard drive, a 128 MB GeForce graphics card, and a flat-screen LCD monitor. The second machine (w2ict2) is the algorithm machine, and resides in the equipment room. WSR-88D data from five radars (KICT, KVNX, KDDC, KINX, and KTWX) are served into the machine in LDM compressed format. NSE data derived from the RUC20 model, if it becomes available, will be FTPed directly from NSSL. The algorithm machine is beefed up with two 2.4 GHz microprocessors, 4 GB RAM, three 36 GB hard drives, and a DVD-R recorder for data and product archiving. Each machine has been speced over and beyond what is needed for a five radar system.

3. *NSSL Staffing and NWSFO Training*

For the shakedown period, the WDSSII will be tested in real-time (both at the WFO and on a mirror system at NSSL) to identify and correct any existing bugs in the system. Also during this time, the Operations Director will travel to the NWSFO to provide training to the Science Operations Officer (SOO), a designated WDSSII Focal Point, and any other NWS staff members. These trained NWS staff members will then be responsible for selecting additional NWSFO staff meteorologists for training on the WDSSII ("train the trainer"). The NSSL staff member will continue to provide assistance in the training of the other NWSFO meteorologists as needed (e.g., "refresher" training through the operations period). **Appendix B contains the "w2 Display User Guide" for reference.**

The Operations Period of each test will be conducted during approximately three months beginning early April 2003 and lasting through 30 June 2003. During most severe weather episodes, at least one NSSL staff member will be on site. This NSSL staff member will be responsible for: 1) ensuring the smooth running of the WDSSII and its associated systems, 2) observing the WDSSII "in action" during warning operations (and carefully documenting the performance of the system), 3) conducting surveys of the NWSFO staff members who used the WDSSII after each shift, and if there is time 4) assisting the NWS staff in conducting real-time verification and post-storm damage surveys. In certain instances during past tests and when conditions permitted, NSSL staff members have actually participated in the real-time warning decision making process, and have also operated the WDSSII. This will be done at the discretion of the NWS staff.

Each NSSL staff member will be supplied with a mobile phone. Because only one NSSL staff member will be on site for any warning operations, they may be working unconventional hours (duration and time of day). During long periods of operation (shifts greater than 8 hours or consecutive days), the NSSL Operations Person can decide (in consultation with the SOO) to cease NSSL's participation for that day.

4. *Daily WDSSII Operations*

On most days during the Operations Period when severe weather is forecast, an NSSL Operations Person will travel from Norman and arrive at the NWSFO by late morning or early afternoon. They will first check the status of the equipment and conduct data archiving for past events (if needed). The NSSL Operations Person will then provide the SOO (or perhaps the Forecaster-In-Charge; FIC) a short briefing on the status of the test or any identified problems, and solicit suggestions concerning the hardware and software.

Once weather with the potential of affecting the NWSFO County Warning Area (CWA) is anticipated in the short-term (via an SPC Mesoscale Discussion, SPC Watch, or WFO Nowcast) or detected by the WSR-88D, the NSSL Operations Person will determine when to begin formal WDSSII test operations.

For a proper evaluation of the WDSSII, NSSL requires that at least one NWSFO meteorologist be positioned at the WDSSII display machine using the display software. When operations switch into a warning mode, the Operations Person's primary duty is to observe and document WDSSII activity. This mode of operation will continue until mutual agreement is met among the participants to end the day's operations. The NSSL Operations Person will be co-located with the NWSFO meteorologists in the "warning area", to observe the use of the WDSSII. The Operations Person may, at the discretion of the SOO or NWSFO staff, be positioned at the WDSSII display machine, to assist in the warning operations. The NSSL Operations Person will carefully document the strengths and weaknesses of the WDSSII. At the completion of the operations mode, the Operations Person will give a short questionnaire (see Appendix A) to the NWS employee(s) stationed at the NSSL WDSSII. The questionnaire will include questions about the effectiveness and usefulness of the NSSL WDSSII. Finally, the Operations Person will determine whether NSSL staff will be assisting in post-storm damage surveys the following day or if they will be remaining in town for a multiple-day event.

Occasionally, the NSSL Operations Person may leave the WFO station (conducting other business in Wichita) while awaiting severe weather. If the NSSL Operations Person is not on station, but in Wichita, and unanticipated severe weather becomes imminent, NSSL requests that the NWSFO staff, particularly the SOO or Forecaster-In-Charge, alerts the NSSL meteorologist of impending warning operations. **Please call the staff member on their mobile phone with at least one hour of lead-time before expected warning operations.** If NSSL staff is not in Wichita, **please contact the NSSL staff (email and mobile phone) with at least 3-4 hours lead-time (if possible) so they can travel to Wichita for operations**. NSSL wishes not to miss any significant warning operations involving the WDSSII, and the WFO staff can provide that needed heads-up.

A phone list will be posted near the WDSSII display machine. It is repeated here:

Greg Stumpf	**greg.stumpf@noaa.gov**	**405-826-8644**
Travis Smith	**travis.smith@noaa.gov**	**405-834-9687**
Kevin Manross	**kevin.manross@noaa.gov**	**918-408-7014**

The staffing schedule will be posted near the WDSSII display machine and be periodically updated. The NSSL staff meteorologists will be staying at one of the local hotels in Wichita if an overnight stay is required (for late events, multiple-day events, or to assist in verification the day after an event). Hotel information will be provided for each event.

NOTE: If a severe weather event occurs in which an NSSL staff member was not present for WDSSII operations, all NWS staff members who used the WDSSII should complete the one-page survey form.

5. Verification

The NSSL staff will undertake an augmented verification effort during the Operations Period. If time permits during real-time operations, the NSSL Operations Person *may* assist the NWSFO staff in collecting verification from spotters via phone calls. The decision to do this will be left at the discretion of the Operations Person and the SOO. NSSL's primary desire is to augment the verification effort by, 1) making calls in the vicinity of un-warned storms, 2) making real-time followup calls to storms which have already verified to determine if severe weather is continuing, and 3) reducing the workload of the NWSFO staff making probing verification calls. The NSSL Operations Person will collect and copy all severe weather data for use by NSSL scientists for post-test algorithm evaluation. Copies will be made of all spotter and warning verification forms.

The NSSL staff members will be available to assist the NWSFO staff in conducting post-storm damage surveys. Typically, the only time NSSL staff would not help would be on some consecutive-storm days when the NSSL staff would be needed for additional warning operations.

6. Event short-reports

The NSSL Operations Person will write informal event short reports (1-2 pages) within a few days after the end of each worked event that an NSSL staff was present. These reports will provide an overview of the weather during that event, with added detail on storm verification. A summary of the WDSSII performance, a technical list of system problems, and a summary of user feedback and system highlights is also to be included. These reports will be distributed via e-mail to all participants and interested parties for comments and feedback.

7. Data Archiving

The WSR-88D radar data will be archived both by the current WSR-88D Level-II recorders (for each radar) and by the NSSL WDSSII. The first archive becomes the official NCDC data set. After each significant weather event, the NSSL staff member will also archive the WSR-88D LDM data and WDSSII products to DVD. This second radar data archive on DVD will be used for post-analysis (and possible training data sets) and becomes the property of NSSL.

8. Post-operations "wrap-up"

For each test site, there will be an experiment "wrap up" about one month after the three-month operational period. NSSL will also conduct a post-test survey. The post-test survey will be a fairly long questionnaire (20-30 pages), and will cover many aspects of the experiment. **The surveys are contained in Appendix A.**

Both the daily and the long-form surveys will be used as feedback to further improve the severe weather applications and the display system.

Although the formal testing will end on 30 June 2003, the WDSSII will remain at the Wichita WFO at least through 30 September 2003. An NSSL meteorologist, at NSSL's discretion, may staff any out-of-season significant severe weather events. Unless project funding is extended into FY04, after 30 September, the WDSSII system hardware will be returned to NSSL and all external data communications will be terminated.

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REFERENCES

Eilts, M. D., J. T. Johnson, E. D. Mitchell, S. Sanger, G. J. Stumpf, A. Witt, K. W. Thomas, K. D. Hondl, D. Rhue, and M. Jain, 1996: Severe weather warning decision support system. *Preprints, 18th Conf. on Severe Local Storms*. San Francisco, CA, Amer. Meteor. Soc., 536-540.

Elmore, K.M, E.D. Albo, R.K. Goodrich, and D.J. Peters, 1994: NASA/NCAR airborne and ground-based wind shear studies. Final Report, contract no. NCC1-155, 343 pp.

Hondl, Kurt, 2002: Current and planned activities for the Warning Decision Support System – Integrated Information (WDSS-II). *Preprints, 21st Conference on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., 146-148.

Johnson, J. T., P. L. MacKeen, A. Witt, E. D. Mitchell, G. J. Stumpf, M. D. Eilts, and K. W. Thomas, 1998: The Storm Cell Identification and Tracking (SCIT) algorithm: An enhanced WSR-88D algorithm. *Wea. Forecasting*, **13**, 263-276.

Lakshmanan, V., 2002: WDSSII: an extensible, multi-source meteorological algorithm development interface. *Preprints, 21st Conf. on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., 134-137.

Lynn, R. J., and V. Lakshman, 2002: Virtual radar volumes: creation, algorithm access, and visualization. *Preprints, 21st Conf. on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., 229-232.

Marzban, C., and A. Witt, 2001: A Bayesian Neural Network for Severe-Hail Size Prediction. *Wea. Forecasting*, **16**, 600–610.

Mitchell, E. D., S. V. Vasiloff, G. J. Stumpf, M. D. Eilts, A. Witt, J. T. Johnson, and K. W. Thomas, 1998: The National Severe Storms Laboratory Tornado Detection Algorithm. *Wea. Forecasting*, **13**, 352-366.

Smith, T. M., K. E. Elmore, and S. A. Myers-Dulin, 2002: An improved Damaging Downburst Prediction and Detection Algorithm for the WSR-88D. *Wea. Forecasting* (submitted).

Stumpf, G. J., A. Witt, E. D. Mitchell, P. L. Spencer, J. T. Johnson, M. D. Eilts, K. W. Thomas, and D. W. Burgess, 1998: The National Severe Storms Laboratory mesocyclone detection algorithm for the WSR-88D. *Wea. Forecasting*, **13**, 304-326.

Stumpf, Gregory J., T. M. Smith, and A. E. Gerard, 2002: The Multiple-Radar Severe Storms Analysis Program (MR-SSAP) for WDSS-II. *Preprints, 21st Conference on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., 138-141.

Witt, A., M. D. Eilts, G. J. Stumpf, J. T. Johnson, E. D. Mitchell, and K. W. Thomas, 1998: An enhanced hail detection algorithm for the WSR-88D. *Wea. Forecasting*, **13**, 286-303.