THE MULTIPLE-RADAR SEVERE STORM ANALYSIS PROGRAM (MR-SSAP) FOR WDSS-II

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1. INTRODUCTION

The National Severe Storms Laboratory (NSSL) has played the primary role in the development and evaluation of severe weather applications for the Weather Surveillance Radar - 1988 Doppler (WSR-88D). NSSL developed many of the primary detection algorithms for the radar. These severe weather applications have included the Storm Cell Identification and Tracking (SCIT) algorithm (Johnson, et al. 1998), the Hail Detection Algorithm (HDA; Witt et al. 1998), the Mesocyclone Detection Algorithm (MDA; Stumpf et al. 1998), the Tornado Detection Algorithm (TDA; Mitchell et al. 1998), and the Damaging Downburst Prediction and Detection Algorithm (DDPDA; Smith et al. 2002).

These five algorithms comprised the Severe Storms Analysis Program (SSAP). 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. 1997) at a variety of National Weather Service (NWS) Forecast Offices (NWSFO) nationwide between the period 1993 through the present year, 2002. Both of these legacy systems, the SSAP and the WDSS, were developed as single-radar "centric" software systems. All algorithm and radar products were keyed to the individual volume scans and individual radars. These restrictions were somewhat imposed upon by the funding primarv institution for the development of these severe weather applications the NEXRAD Radar Operations Center (ROC) - who is mandated to only support development and

integration of single-radar data source meteorological applications for the WSR-88D.

Even with the limitations of singlesource 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 (including SCIT, HDA, TDA, soon MDA in the Fall 2003). This concept continues to be used to test improvements and additions to severe weather analysis applications at NSSL. We will describe current improvements to the SSAP as well as the real-time testing proposed to evaluate these improved algorithms.

2. MULTI-RADAR SEVERE WEATHER ALGORITHM IMPROVEMNTS

NSSL is currently developing major improvements to these severe weather algorithms as well as developing a variety of new applications to detect and diagnose severe weather. The traditional WSR-88D severe weather algorithms within the legacy SSAP 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.) as well as other input from severe weather Therefore, these traditional applications. single-radar severe weather algorithms are

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being updated to take advantage of additional data sources, including input from multiple radars, in order to reduce the uncertainty of the measurements and increase the accuracy of the diagnoses of severe weather.

The Multiple-Radar Severe Storms Analysis Program (MR-SSAP) extends the concepts of all 5 of these algorithms into the multiple-radar (and 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 detections. 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 quidance. Second, storm and tornado evolution can typically be very rapid, and 5or 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. The vertical and time association is then performed at regular

intervals with the last several minutes of 2D features using a "virtual volume scan" concept (Lynn 2002) to enable rapidlyupdating algorithm output and timesynchronization of the multiple-radar data. Our version presently updates the output at every 60 seconds. Faster updates are possible, but we feel that this update rate may initially overwhelm NWS warning forecasters. Real-time testing will be used to determine an optimal update rate. During the diagnosis phase of the 3D detections, range-dependent sampling differences are accounted for when combining both the reflectivity- and Doppler velocity-produced features. The MR-SSAP is also independent of radar volume coverage pattern and will operate in rapidly updating fashion with even just one radar source (if there are outages or regions of only single radar coverage).

Figure 1 shows an example of a SCIT detection from the MR-SSAP. Single-radar SCIT detections of the same storms from the three individual WSR-88Ds sensing the storm are shown in Figs. 2-4 for comparison. The SCIT tracks for each detection are overlaid. Note the more frequent reporting of the multi-radar SCIT detections from MR-SSAP than for the single-radar counterparts. Also note that the MR-SSAP cell locations have been updated four times since the time of the KTLX lowest-elevation tilt due to the addition of multiple radar data. This gives 4 minutes more lead time than the single-radar SCIT running with just KTLX data.



Figure 1. Multiple-radar SCIT output for 20 May 2001 at 20:51:56 UTC using KTLX (Twin Lakes OK), KINX (Tulsa OK) and KSRX (Fort Smith) WSR-88Ds. Reflectivity from KTLX (at 20:47:15 UTC) and 0.5° elevation and current and 1-minute increment past cell centroid locations are shown.



Figure 2. Single-radar SCIT output for 20 May 2001 at 20:47:15 UTC using KTLX WSR-88D. Reflectivity (at same time) and 0.5° elevation and current and 5-minute increment past cell centroid locations are shown.



Figure 3. Single-radar SCIT output for 20 May 2001 at 20:47:13 UTC using KINX WSR-88D. Reflectivity (at same time) and 0.5° elevation and current and 5-minute increment past cell centroid locations are shown.



Figure 4. Single-radar SCIT output for 20 May 2001 at 20:50:14 UTC using KSRX WSR-88D. Reflectivity (at same time) and 0.5° elevation and current and 5-minute increment past cell centroid locations are shown.

3. USING WDSSII TO SUPPORT ALGORITHM DEVELOPMENT

The Warning Decision Support System -Integrated Information (WDSS-II; Hondl 2002, Lakshman 2002) greatly facilitated the development process of the MR-SSAP. The WDSSII 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 earthrelative 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 (API) within the WDSSII development environment were utilized to time-synchronized provide access to 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 objectoriented 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 WDSSII and MR-SSAP are designed using economical Linux systems.

4. PROOF OF CONCEPT TEST OF MR-SSAP AT THE JACKSON MS NWSFO

NSSL has provided an operational multiple-radar WDSS for the Jackson Mississippi NWSFO since 1998. The system operates using four independent legacy WDSS each running an independent SSAP for each radar (KJAN - Jackson MS. KMOB - Mobile AL, KLIX - Slidell LA, and KGWX – Columbus MS). The primary objective of the system was to mitigate a partial beam-blockage of the low-altitude elevation scans in a sector east of KJAN by integrating data from other radars scanning the same sector. A low-altitude reflectivity mosaic was developed that filled in the beam-blocked area east of KJAN. The CWA Table was also used to present information regarding the "best radar" to use when looking at individual storm and mesocyclone/TVS detections.

The NSSL and the Jackson NWSFO will jointly conduct a Proof-of-Concept Test (PoCT) to test the new experimental multiple-radar algorithms described in this manuscript. Jackson is the first NWSFO testbed of the MR-SSAP. We will be testing concepts in a "rapid-prototyping" mode; development and improvement of the algorithms and display systems is an ongoing process and we will be updating the system as soon as new techniques are developed. At the time of this publication, NSSL was in the process of procuring the hardware for a Linux system to run the WDSSII and MR-SSAP, and the test is panned to begin early Summer 2002. An intensive operations period, which will be staffed by visiting NSSL scientists, will occur during Mississippi's autumn severe weather peak season in November 2002.

We will 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-ofconcept 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 and product display development prior to their inclusion into NWS systems. For example, the Southeastern U.S. climatology should allow NSSL to determine if the experimental algorithms are region-independent.

The PoCTs also provide operational experience to NSSL meteorologists and developers during real-time warning situations in order to better understand user requirements, and foster collaboration between NSSL scientists and operational meteorologists. The algorithms will each be evaluated qualitatively via feedback questionnaires from the NWS personnel. 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 operational use by NSSL staff. This feedback is very important to help NSSL determine how the algorithm output will be displayed on future operational systems.

5. FUTURE WORK

The Multiple-Radar SSAP represents only the first phase of improvements for the experimental NSSL severe weather A rudimentary Near-Storm applications. Environment (NSE) algorithm is already in use with our legacy SSAP systems. The NSE algorithm calculates a number of mesoscale model sounding parameters (e.g., height of the freezing level) for input into some of the algorithms (e.g., HDA). We plan to expand the use of input from other sensors into the algorithms (including lightning, surface, and satellite data) for a fully multiple-sensor suite of applications.

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References are available upon request.