7B.2

REAL-TIME SEVERE CONVECTIVE WEATHER WARNING EXERCISES AT THE 2010 EXPERIMENTAL WARNING PROGRAM (EWP2010)

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1. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed's (HWT) Experimental Warning Program's (EWP) purpose is to integrate National Weather Service (NWS) operational meteorologists, and National Severe Storms Laboratory (NSSL) researchers to test new science, technologies, products, and services designed to improve short-term (0-2 hour) warnings and nowcasts of severe convective weather threats (Stumpf et al. 2005, Stumpf et al. 2008). The HWT provides a conceptual framework and a physical space to foster collaboration between research and operations to test and evaluate emerging technologies and science for NWS hazardous weather warning operations.

The objective of the EWP Spring Programs is to evaluate the accuracy and the operational utility of new science, technology, products, and concepts in a testbed setting in order to gain feedback for improvements prior to their potential implementation into NWS severe convective weather warning operations. The testbed also provides forecasters with direct access to the latest developments in meteorological research. The testbed also helps researchers and developers to understand operational forecast and warning requirements.

The EWP conducted its fourth formal Spring Experiment during a nine week period in 2010 at the National Weather Center in Norman, OK; hereafter this experiment is referred to as EWP2010. The first five weeks of the experiment were devoted to the feasibility of using new phased-array and gap-filler radar technology for warning decision making, and are covered elsewhere (LaDue et al. 2010, Heinselman et al. 2011, Brotzge and Lemon, 2010). Instead, this paper will focus on the later four-week "Phase II" of EWP2010, in which visiting NWS forecasters used experimental data and products to issue warnings during real-time weather events.

During Phase II of EWP2010, there were two related projects geared toward WFO severe weather nowcast and warning operations, 1) an evaluation of experimental Multiple-Radar / Multiple-Sensor (MRMS) severe weather applications, and 2) an evaluation of experimental satellite applications designed to be proxies for future Geostationary Operational Environmental Satellite series R (GOES-R) applications.

Visiting NWS forecasters used the experimental data during real-time severe weather operations in which they issued NWS-format Severe Thunderstorm Warnings and Tornado Warnings. User comments were collected during shifts, online questionnaires were given at the end of shifts, and discussions occurred during post-event de-briefings. The NWS feedback on this test is most important for future development for the NWS and eventual implementation of new application, display, and product concepts into AWIPS2 and other operational systems.

2. EXPERIMENTAL DATA/PRODUCTS

2.1 *Multiple-Radar / Multiple-Sensor (MRMS) severe weather applications*

Throughout the 1980s and 1990s, the National Severe Storms Laboratory (NSSL) and its partners developed most of the original radar-based algorithms for the WSR-88D. The original storm algorithms were based primarily on one data source - a single WSR-88D radar, and are thus subject to the limitations imposed by the single radar paradigm, i.e. the cone-of-silence, beam broadening at far ranges, terrain blockage, ground clutter, anomalous propagation, bright-banding, and volume product latency.

There are numerous locations within the U. S. which are covered by more than one WSR-88D, particularly across the Midwest and Northeast high-population corridors (Fig. 1). These areas of overlapping coverage represent a vastly under-utilized data source for NWS operations, proper exploitation of which could greatly mitigate the limitations listed above.

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Figure 1. WSR-88D coverage over the Continental U.S.

In the past decade there has been an evolution in the warning decision paradigm from one in which forecasters base most of their warning decisions on mainly single radar data to one in which warning forecasters manually integrate an ever-expanding “fire hose” of all available basic meteorological information from multiple radars and multiple sensors (surface, upper air, satellite, lightning, model data). In the future, this information will involve even more-rapidly refreshing data streams of radar (e.g., phased-array radar), satellite (GOES-R), and lightning (LMA) data. *Even today, the volume of radar data alone is such that it is nearly impossible for a well-trained meteorologist to be assured they have interpreted all of the relevant information.*

To address the above operational needs, NSSL developed a multiple-radar / multiple-sensor (MRMS) severe weather algorithm framework during the early 2000s (Lakshmanan et al. 2006). The storms which form and/or move through these parts of the network can be scanned by multiple WSR-88Ds providing better detection accuracy and potentially leading to a higher warning Probability of Detection. MRMS algorithms can also refresh their integrated data sets more rapidly than a single WSR-88D volume scan, potentially lead toward improved warning lead time. A NWS warning decision paradigm supplemented with MRMS algorithm output could provide better continuity of operations in the event one of the sensors fails, by automatically filling data from other sensors. Figures 2 and 3 illustrate comparisons between using single radar data and multiple radar integration for storm analysis.

Automated MRMS algorithms quickly and intelligently integrate the numerous remotely-sensed data streams that the NWS meteorologist must currently analyze manually (a time-consuming process), saving time and providing a more robust threat assessment leading to improved warning verification scores. The most reliable algorithms might also be used in “autopilot mode” to handle the more-routine warning decisions (e.g., hail) in order to better allocate WFO staff resources to better manage the challenging warning decisions (e.g., tornadoes) and customer support, providing more robust decision support services for high impact events.

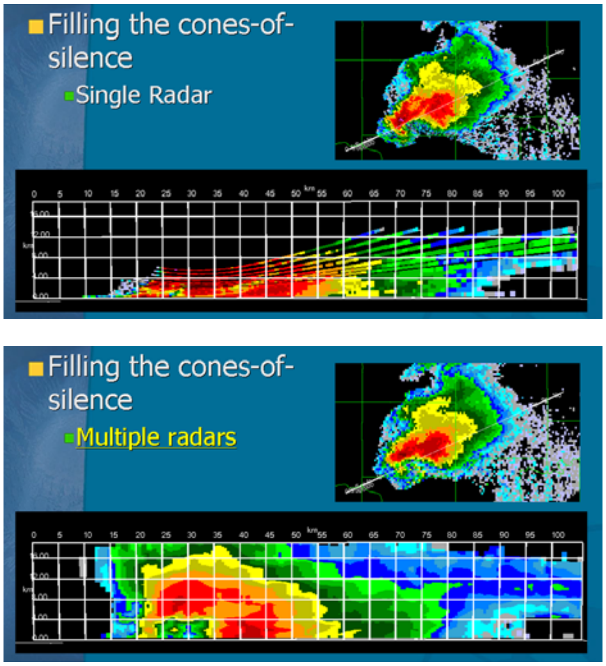

Figure 2. Horizontal and Vertical cross-section of a supercell storm on 8 May 2003 in Oklahoma that passes into the cone-of-silence of the KTLX WSR-88D. (a) Single radar data from KTLX; (b) Multiple-radar data, from KTLX, KINX, KVNX, KFDR, and the OKC TDWR.

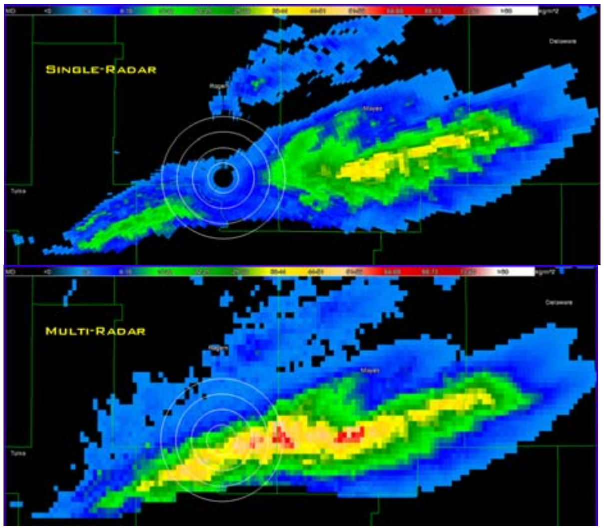

Figure 3. “Swath” of maximum Vertically Integrated Liquid (VIL) over a 180-minute period for a severe storm passing over the KINX (Tulsa, OK) radar site on 22 April 2004; (a) single-radar data only (KINX, location shown by concentric circles), (b) multiple-radar data.

The development and evaluation of the NSSL MRMS algorithms has been facilitated by the NSSL Warning Decision Support System – Integrated Information (WDSSII; Lakshmanan et al. 2007) which mosaics data from multiple radars into rapidly-refreshing four-dimensional (4D) data cubes. The method to combine these data essentially applies an inverse distance weighting function to each radar that is sensing a particular 3D grid cell to provide a resulting data value. The basic 4D data cubes include reflectivity with a resolution of 1 km, and azimuthal shear with a resolution of 500 m (Smith and Elmore, 2004). At each 2-minute update interval, the latest elevation scan data from all radars in the network are used in a "virtual volume scan" fashion to create a new set of grids.

WDSSII multiple-radar 3D grids are integrated with near-storm environment (NSE) information from rapidly-updating numerical model analysis fields to produce a variety of multiple-sensor, high-resolution gridded severe weather products useful for diagnosis of hail, microbursts, tornadoes, and lightning initiation (e.g., height of the 50 dB*Z* echo above the 0°C level; this and other examples shown in Fig. 4). Experimental MRMS algorithms that are particularly popular with NWS users include gridded "Hail Swath" and "Rotation Track" products. These provide the tracks and trends of dangerous supercell storms (Figs. 5 and 6). See Table 1 for a list of key MRMS products.

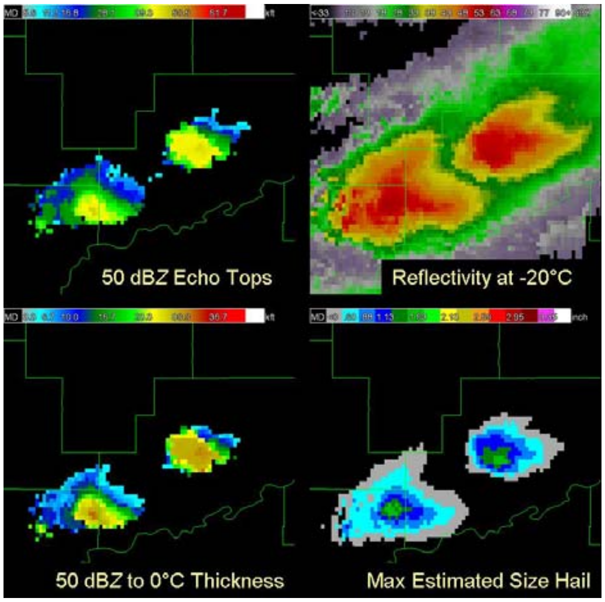

Figure 4. Sample MRMS products for two supercell storms in eastern Oklahoma on 20 May 2001.

2.2 GOES-R proxy satellite products

Products generated from current satellite-based, land-based and numerical model-based datasets are used as proxies to help demonstrate GOES-R products for use in severe convective weather nowcast and warning operations. These products, with examples shown in Figure 7, include:

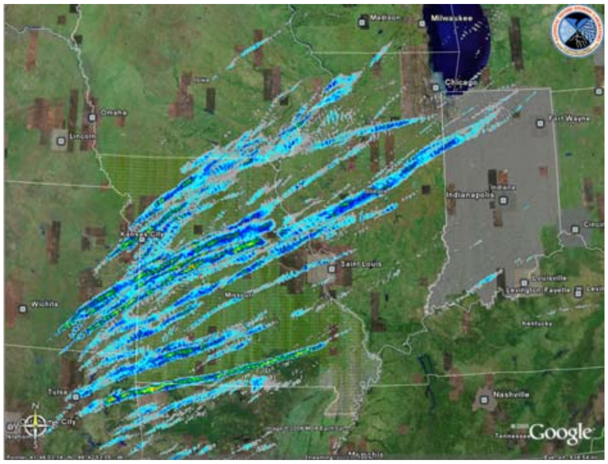

Figure 5. MRMS "Hail Swath" product for the severe weather outbreak of 12 March 2006. The tracks represent maximum estimated hail size over a 12 hour period centered on the storm outbreak.

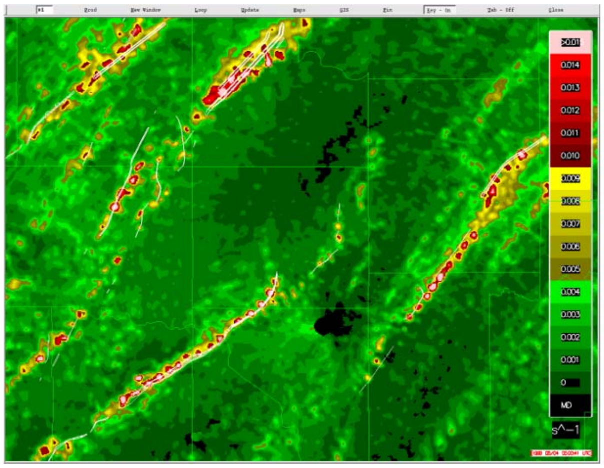

Figure 6. MRMS "Rotation Tracks" product for the 3 May 1999 Central Oklahoma tornado outbreak. The tracks represent maximum estimated hail size over a 6 hour period centered on the storm outbreak. The white lines indicate the actual tornado paths as determined by post-event surveys.

Convective Initiation (CI): Utilizes GOES-13 infrared (IR) window brightness temperature changes based on an operational day/night cloud mask to infer cloud-top cooling as a proxy for vertical development in growing cumulus clouds.

Overshooting Top (OT): Utilizes GOES-13 IR window brightness temperature spatial testing to identify overshooting-top features within mature convective storm cloud-tops.

Thermal Couplet (TC): Utilizes GOES-13 IR window brightness temperature spatial testing to identify thermal couplet (also known as enhanced-V) features within mature convective storm cloud-tops.

Pseudo Geostationary Lightning Mapper (PGLM): Utilizes total lightning data from three Lightning Mapping Array (LMA) networks (Central Oklahoma, Northern Alabama, and Washington DC) and the Lightning Detection and Ranging (LDAR) network (Kennedy Space Center, Florida) that detect VHF radiation from lightning discharges. The real-time lightning data was available in 1 or 2-minute intervals, depending on the network, and sorted into flashes. Following flash sorting, a Flash Extent Density product was created at 8-km resolution to match that expected by the GOES-R GLM.

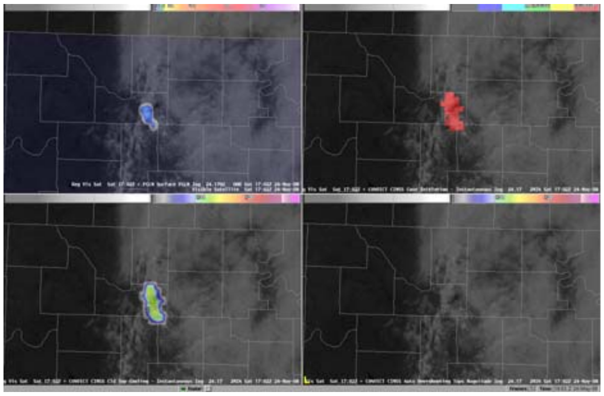

Figure 7. AWIPS 4-panel display of the GOES-R proxy products provided within the EWP including 8-km Pseudo-GLM (top left), convective initiation (top right), cloud-top cooling rate (bottom left), and overshooting-top magnitude (bottom right) over northern Oklahoma on 24 May 2008.

3. EXPERIMENT LOGISTICS

3.1 Participants

Seventeen NWS forecasters representing four of the six NWS Regions participated as evaluators in EWP2010 (Eastern, Central, Southern, Western). Their operational expertise was tapped in order to provide constructive criticism of any aspect of the experiment. Figure 8 shows EWP participants issuing experimental severe weather warnings during a real-time event.

The EWP2010 management team consisted of an Operations Coordinator responsible for the experiment logistics, two Information Technology Specialists, and the two EWP Team Leaders (from the NSSL and the NWS WFO Norman) responsible for the overall management of the EWP. Weekly Coordinators were in charge of the day-to-day scheduling of operations, and led the pre-shift weather briefings and post-shift discussions. Cognizant scientists for each of the experiments were available to assist the visiting participants and provide information and guidance on the particular experiments. They worked closely with the forecaster/evaluator participants during training, operations, and debriefings.

Figure 8. Visiting forecasters issuing experimental severe convective weather warnings during real-time operations in the EWP.

3.2 Operations Periods

The four-week operational experiment was conducted across the period from 17 May 2010 through 18 June 2010, with a break during the Memorial Day week. A fresh set of forecaster participants was available for each one-week period.

Operational activities took place during the week Monday through Thursday (Tuesday – Thursday during the Memorial Day week) within a fixed 1-9 pm shift. Each operations day began with a weather briefing which included a post-mortem discussion of the previous day operations, a discussion of the severe weather outlook for the current day, and the schedule for the current day operational shift (e.g., training periods, real-time experiment locations, archive case playback, etc.). On the first experiment day of each week, several project orientation seminars were delivered. An end-of-week two-hour summary debriefing took place each Friday morning from 10am-12pm.

Most operational days included an Intensive Operations Period (IOP) where the forecasters were immersed in live data in a testbed severe weather warning environment. Every available day saw real-time operations somewhere in the CONUS. New for this year, IOPs were conducted for up to 6 hours (versus a maximum of 3 hours in previous years), because the forecasters felt comfortable with the longer operational shifts. Feedback was obtained from the forecasters during live and archive playback operations through the use of online questionnaires, discussions during the shifts, and during the post-mortem debriefings.

3.3 Technology

The operational experiments were conducted in the HWT Operations Area, which is a room located between the forecast operations areas of the Norman, OK NWS Weather Forecast Office and the NWS Storm Prediction Center (Fig. 9). This room is equipped with a variety of technology to support real-time experiments:

Central to EWP2010 operations was an Advanced Weather Information Processing System (AWIPS) server that processed live radar from any WSR-88D location, and national satellite, lightning, upper air, surface, and mesoscale model data. The server ingested the live experimental data sets from the MRMS and GOES-R systems, making them displayable from the AWIPS Volume Browser. There were also six workstations that could run the D2D display. The AWIPS system could be "localized" to any Continental U. S. NWS Weather Forecast Office (WFO). The AWIPS system's Warning Generation (WarnGen) application was used by the forecasters to issue their experimental severe weather warnings.

The EWP Situational Awareness Display (SAD) consists of six large flat-screen monitors that display the output from any of the experiment workstations (Fig 10). A video server was used to display local television broadcasts and live storm-chaser video feeds. Other output, such as Google Earth images with radar and spotter overlays, and near-storm environment maps, were displayed when needed.

3.4 Communication and Outreach

There are several Web resources used to communicate EWP information. The EWP Main Web site:

http://ewp.nssl.noaa.gov/

contains links to general information about the EWP, and results from past spring experiments.

An internal EWP web page, accessible by experiment participants and NOAA employees (via their LDAP user accounts) is available at:

https://secure.nssl.noaa.gov/projects/ewp2010/

The internal page includes links to the operations manuals and PowerPoint briefings for each experiment, and the EWP Blog:

https://secure.nssl.noaa.gov/projects/ewp/blog/

The EWP Blog was used to communicate the daily activities during the experiment. This included the daily weather briefing outlooks, post-mortem summaries (daily and weekly), as well as "live blogs" that were recorded during the actual operations.

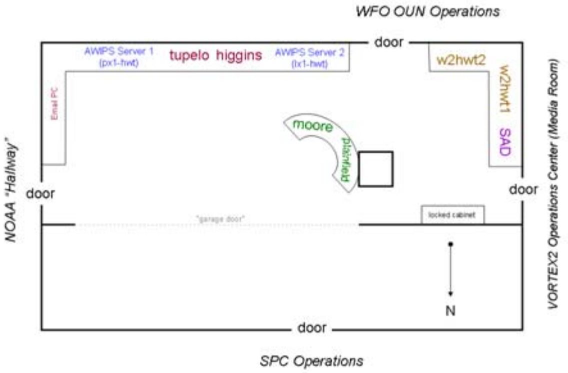

Figure 9. Diagram showing the layout of the Hazardous Weather Testbed during EWP2010.

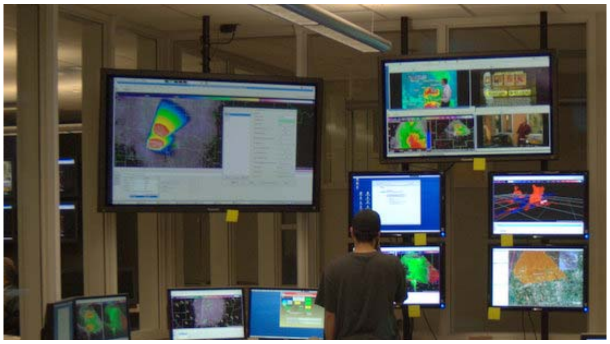

Figure 10. The EWP Situational Awareness Display.

4. OPERATIONS

With the main objective of EWP2010 Phase II to evaluate the accuracy and operational utility of the experimental MRMS and GOES-R data and products in supporting warning decision making, we aimed to answer the following research questions:

- How can the experimental products be used to produce more efficient, more precise, and more accurate severe weather warnings?
- What are the operational impacts of the experimental products on the warning decision process?
- Do the automated MRMS products offer faster analysis time versus "traditional" manual AWIPS base data analysis procedures (e.g., "all-tilts", "4-panels"), and will this improve situational awareness during events with many storms or rapidly-evolving storms?
- Do the MRMS products offer improved guidance in "radar hostile" regions (cones-of-silence, distance from radars, terrain blockage)?

- Does repeated use and increased familiarity of the MRMS products over time steadily improve warning decision making?

- How can the experimental products be improved?

- What new experimental products should be developed?

To answer these questions, the visiting NWS forecasters issued experimental Severe Thunderstorm Warnings and Tornado Warnings using the EWP AWIPS workstations during live events, with the overall objective of "beating" the official severe weather warnings being issued by the actual NWS forecast offices for the same events. The forecasters were not allowed to receive any information about the official NWS products for the same events. During EWP warning operations, the forecasters were provided access to base data on their AWIPS workstations, as well as the experimental EWP2010 data sets. The forecasters were also fed actual storm reports from a variety of sources, and in some cases had access to live views of the storms via webcams, television feeds, and streaming storm chase dash cams.

The "EWP Warning" data was collected, along with the official NWS warning data with the intent to carry out a quantitative comparison analysis to assess the following:

- Improvements in **Probability Of Detection (POD)**, in other words, fewer missed events.

- Improvements in **Lead Time** due to the fast automated integration of MRMS data for each storm at rapid updates.

- Improvements in polygon coverage - or smaller **false alarm area**.

- Improved **polygon orientation** along the storm paths.

- Improved **estimation of storm intensity** (hail size, wind speed) in warnings.

In addition to the quantitative warning comparison, qualitative feedback was captured from the forecasters via an end-of-shift online survey and discussions during the real-time events and during post-mortem briefings.

5. CONCLUSIONS

5.1 MRMS survey results

Many of the MRMS survey questions asked the forecasters to rate specific aspects of the experiment on a scale of 1 to 10 with 10 being the most positive result. Of these three survey questions, composite day-of-week average survey responses were calculated and plotted in Figure 12:

a) Rate the concept of multi-radar / multi-sensor applications for warning decision-making

b) How often did you use the multi-radar / multi-sensor products during today's experimental warning operations?

c) Does having the new multi-radar / multi-sensor products make your warning decisions slower, the same, or faster?

The results indicate that trust and familiarity of the MRMS products increased during each forecaster's week of participation.

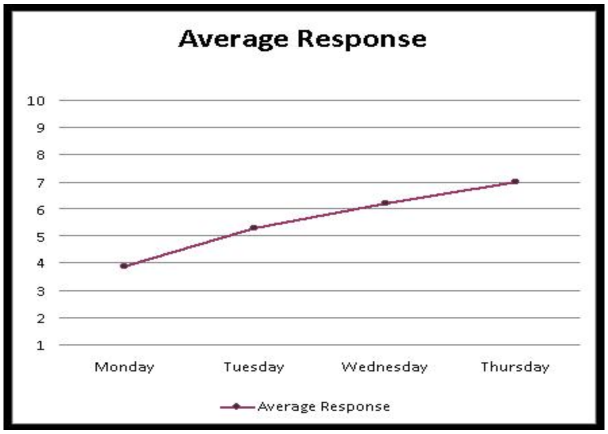

Figure 12. Average response to the three survey questions by day of week.

We also asked the forecaster to rank - on a scale of 1 to 10 - the most popular MRMS products used to augment their warning decision making. In this order, here are the top products:

- Reflectivity at -20°C height
- Height of 50 dB*Z* Echo Top above -20°C height
- Max Estimated Size of Hail (MESH)
- 50 dBZ Echo Top Height
- MESH Swath
- Reflectivity at -10°C height
- Azimuthal Shear
- Rotation Track (Azimuthal Shear Swath)

Several of the questions asked forecasters to provide written comments. An overwhelming majority of responses indicated that the MRMS grids greatly augmented and raised the confidence of warning decisions by allowing the algorithms to rapidly perform certain tasks, thus permitting the human forecaster to focus on the more-difficult warning decisions. For example, a popular product like the Height of 50 dB*Z* Echo Top above -20°C height can be deduced via traditional base data analysis methods using "all-tilts" or

"4-panels" along with data sampling using the AWIPS display. However, this process is tedious, especially when considering multiple storms at each radar volume scan update, and for multiple radars if storms are sampled thusly. Using the corresponding MRMS product, the same result is obtained automatically, and the forecasters merely had to look at the product to easily pick out the most severe storms that required attention. Another example, using the MESH product, is shown in Fig. 13.

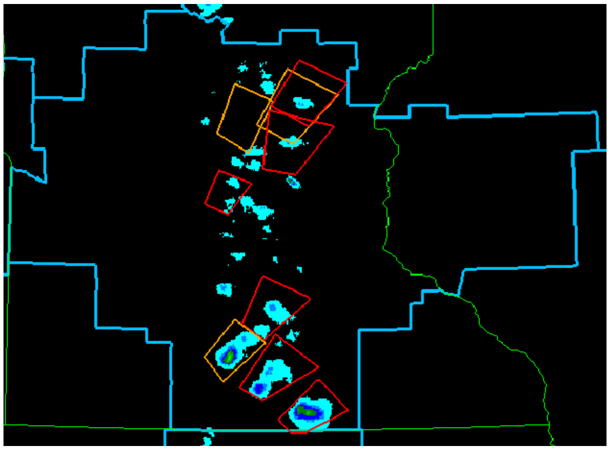

Figure 13. The Maximum Estimated Size of Hail (MESH) product for the Minneapolis WFO portion of the 17 June 2010 MN/ND severe weather outbreak event. Overlaid are the warning polygons at that time as issued by the EWP forecasters (orange: Severe Thunderstorm Warning; red: Tornado Warning).

The forecasters also indicated that the hail swath and rotation tracks products significantly aided in the positioning of their storm-based warning polygons such that hazard threat areas were less-likely to exit the warning polygon areas and move into unwarned locations. This leads to reduced false alarm area and fewer missed portions of storm hazard areas. Note from Fig. 14 that the experimental warning polygons (left) are more closely aligned with the motion of the storm tracks, leading to better representation of the weather hazard. This aspect is also treated in our quantitative warning comparison analysis.

5.2 GOES-R Results

Summaries of the GOES-R proxy product feedback are provided by Gurka et al. (2010) and Kuhlman et al. (2010).

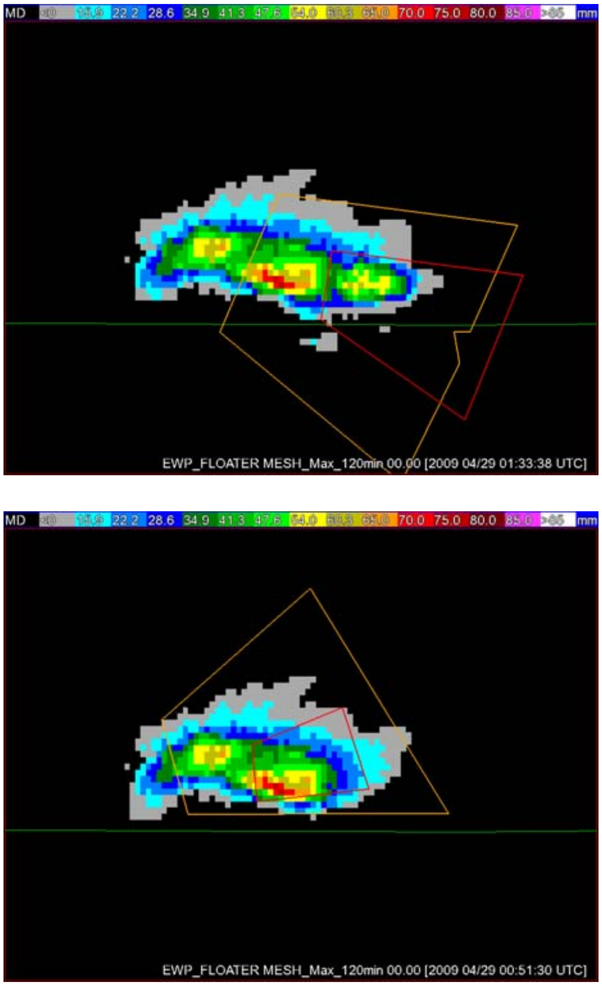

Figure 14. MRMS "Hail Swath" product for a supercell event in southeast New Mexico on 28 April 2009. The top figure shows the experimental warnings (orange = severe; red = tornado) issued by forecasters during exercises in the 2009 spring HWT experiment. The bottom figure shows the official NWS warnings for the same event.

5.3 Preliminary quantitative warning comparison results

Work is currently underway to develop the framework for comparing the warnings issued by our EWP visiting forecasters and the official NWS warnings issued for the same events. Since our objectives include metrics that are not part of the official government performance measures, the analysis is not going to follow the "traditional" warning verification methods. Currently, warning polygon areas are verified using single point ground truth reports.

Instead, the verification will be performed geospatially, on a 1 km by 1 minute grid. For each grid point, a time line of hazard observations (from ground truth) and hazard forecasts (warning polygons) can be constructed, and the following grid-point specific measures can be computed:

- Probability Of Detection (POD)
- False Alarm Rate (FAR)
- Critical Success Index (CSI)
- Heidke Skill Statistic (HSS)
- False Alarm Area (FAA)
- False Alarm Time (FAT)
- Lead Time (LT)
- Departure Time (DT)
- Valid Warning Time (VWT) percentage

Preliminary results from our most significant event of EWP2010, the 17 June 2010 Minnesota and North Dakota severe weather outbreak, are used to develop this new verification framework. Only the tornado verification has been treated thus far; hail and wind verification will be treated next. To score Tornado Warnings, the following analysis is performed:

- Convert Tornado Warning polygons to a "forecast grid" at every 1 km and 1 minute.

- Create a similar "observation grid" from tornado storm reports. The locations of the tornadoes are augmented by radar data to interpolate position every 1 minute.

- "Splat" the tornado reports by any distance in order to allow for some degree of "closeness" in the warnings. For the initial analysis, we'll choose a splat distance of 10 km.

At each grid point and time interval, the condition of the forecast and observation is recorded to a 2 x 2 contingency table of hits, misses, false alarms, and correct null events, in order to compute the above verification measures. Spatially, a sample grid would look like the example in Figure 15.

At the time of this publication, the analysis indicates that the EWP warnings are more accurate than the NWS warnings for the same storms and same warning operational periods. However, the results are too preliminary to present in this paper, and will be later reported at the 24th Conference on Weather and Forecasting in January 2011 (Stumpf et al, 2011).

In addition to the geospatial warning analysis, for the 17 June 2010 event we have conducted comparisons of warning polygon orientation and warning intensity estimates (the latter only using hail reports, due to the lack of severe wind reports for that day). Both of these analyses also indicate that the EWP warnings outperformed the official NWS warning by these measures. Again, the results are too preliminary to include in this paper and will be reported later (Stumpf et al, 2011).

5.3 *Research transition to operations status*

The past 8 years of operational testing of the algorithms, culminating with the 2010 Hazardous Weather Testbed real-time experiment, have indicated that the NSSL MRMS algorithm system is the most mature warning R&D technology available for transition to WFO operations. In addition to the WFOs, there are a number of other stakeholders that stand to benefit from the MRMS system, including aviation, hydrology, and numerical weather prediction. Therefore, the NWS Operations and Services Improvement Process (OSIP) has been initiated to transition the MRMS research system to operations. The decision to deploy an MRMS operational system at the National Center for Environmental Prediction (NCEP) will be made by the end of the 2010 calendar year.

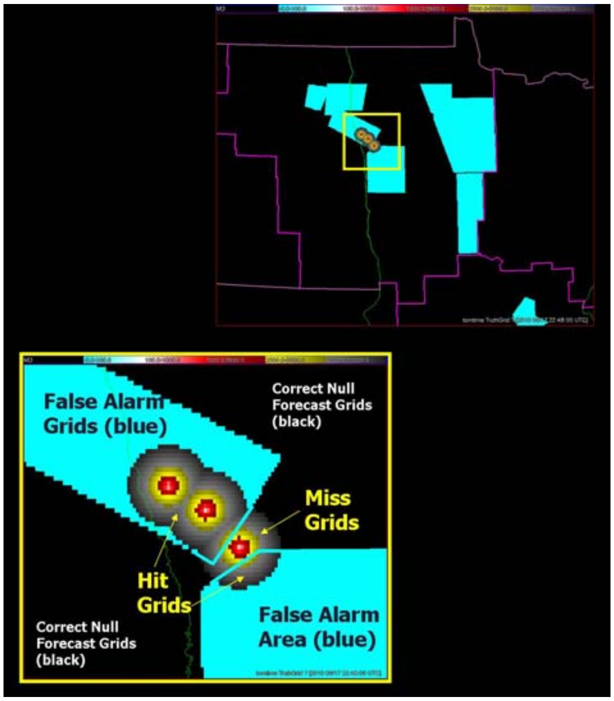

Figure 15. Inset shows a forecast grid (converted Tornado Warning polygons) overlaid with an observation grid ("splatted" tornado locations – diameter of 10 km) near Grand Forks ND at 2252 UTC on 17 June 2010. The corresponding 2x2 contingency table conditions of hit, miss, false alarm, and correct null, are indicated.

6. ACKNOWLEDGMENTS

EWP2010 Phase II wouldn't have been possible without contributions from a number of individuals and organizations. Those from the National Oceanic and Atmospheric Administration (NOAA) include: the National Severe Storms Laboratory (NSSL) Radar Research and Development Division and the NSSL Warning Research and Development Division; the

National Weather Service's Meteorological Development Laboratory (MDL); the NWS Warning Decision Training Branch, and the NWS Weather Forecast Office in Norman, OK.

In particular the following individuals should be cited: Kiel Ortega, Don Burgess, Pamela Heinselman, Brenda Philips, Jerry Brotzge, Ellen Bass, Jeff Brogden, Charles Kerr, Valliappa Lakshmanan, Karen Cooper, Vicki Farmer, Paul Griffin, Brad Sagowitz, Brian Schmidt, John Ferree, Kevin Scharfenberg, Steve Irwin, and Patrick Marsh.

We thank our National Weather Service operational meteorologists for participating as evaluators in this experiment (and we also thank their local and regional management for providing their staff time). They are: David Blanchard (WFO Flagstaff, AZ), Matthew Kramar (WFO Sterling, VA), Ken Pomeroy (NWS Western Region HQ, Salt Lake City, UT), Darren Van Cleave (WFO Rapid City, SD), Rod Donavon (WFO Des Moines, IA), John Murray (WFO New York, NY), James Sieveking (WFO St. Louis, MO), David Zaff (WFO, Buffalo, NY), Frank Alsheimer (WFO Charleston, SC), Dan Darbe (WFO Peachtree City/Atlanta, GA), Daniel Nietfeld (WFO Omaha, NE), Pat Spoden (WFO Paducah, KY), Andy Taylor (WFO Norman, OK), Angie Lese (WFO Louisville, KY), Melissa Kreller (NWS Southern Region HQ, Fort Worth, TX), Marcus Austin (WFO Tallahassee, FL), David Sharp (WFO Melbourne, FL).

The HWT management committee members (Mike Foster, Russ Schneider, and Jeff Kimpel), Kevin Kelleher (NSSL), Kurt Hondl (NSSL), Doug Forsyth (NSSL), Ed Mahoney (WDTB), and Stephan Smith (MDL) were instrumental in providing the necessary resources to allow the EWP spring experiment happen. This work has been primarily funded via sources from the National Severe Storms Laboratory, the National Weather Service Meteorological Development Laboratory, the NWS Warning Decision Training Branch, and via NOAA-OU Cooperative Agreement #NA17RJ1227.

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Table 1: A selection of key WDSSII multiple-radar/multiple-sensor (MRMS) algorithms and products for severe weather warning decision assistance.

Acronym or Name	*Algorithm/Product Description*
GHDA	**Gridded HDA** - Diagnoses Probability Of Severe Hail (POSH) and Maximum Expected Size of Hail (MESH) for each grid point's reflectivity profile on the 3D MR Ref Grid and temperature profile information interpolated from each 2D grid point on the RUC 00h analysis field. Provides 2D geospatial grids of POSH and MESH.
Hail Swath	**Hail Swath** – Maximum MESH values at each grid point for a specific time period (e.g., 30-min, 120-min; could be any interval). Result is geospatial coverage of hail size. Product is provided in the NSSL On-Demand Verification System.
LLSD	**Linear Least Squares Derivative** – Sophisticated technique for deriving scalar azimuthal and radial shear values from single-radar Doppler velocity data.
MaxAzShrLayer	**Maximum Azimuthal Shear in a Layer** – The maximum LLSD azimuthal shear in a layer above ground level (AGL) for a specific time within the 3D MR AzShr grid. Currently, a low-altitude (0-2 km AGL) and a mid-altitude (3-6 km AGL) maximum shear product are produced, but the MRMS framework allows for MaxAzShr products for any defined layer.
Rotation Track	**Rotation Track** - Maximum MaxAzShrLayer values (for any layer) at each grid point for a specific time period (e.g., 30-min, 120-min; could be any interval). Result is geospatial coverage of estimated track of rotation signatures in severe storms. The 0-2 km AGL Rotation Track product is provided in the NSSL On-Demand Verification System.
MR-ET18, MR-ET30, MR-ET50	**Multiple Radar Echo Tops** – The maximum height of the 18, 30, and 50 dB*Z* echoes for each grid point on the 3D MR Ref Grid. The MRMS framework allows for different MR-ET products, with varying reflectivity thresholds.
MR-VIL	**Multiple Radar VIL** – Integrates the vertical profile of reflectivity for each grid point on the 3D MR Ref Grid. The MRMS framework allows for different MR-VIL products, with varying ice-contamination caps (e.g., Reflectivity > 56 dB*Z*), or no cap.
MR-VILD	**Multiple Radar VIL Density** – Integrates the MR-VIL and MR-ET product for each grid point on the 3D Ref Grid. The MRMS framework allows for different MR-VILD products, with varying MR-VIL and MR-ET products.
LRA	**Layer Reflectivity Average** - Integrates the 3D Ref Grid with RUC temperature profiles to determine the average, maximum, or summation of reflectivity within any constant altitude, temperature, or pressure layer (e.g., LRA between 0°C and -20°C). Useful for lightning initiation and hail diagnosis.
ITR	**Isothermal Reflectivity** – Integrates the 3D Ref Grid with RUC temperature profiles for reflectivity products on constant temperature altitudes (e.g., 0°C, -10°C, -20°C). Useful for lightning initiation and hail diagnosis. The MRMS framework allows for different products at any temperature altitude.
ITRT	**Isothermal Reflectivity Thickness** - Integrates the 3D Ref Grid with RUC temperature profiles to determine layer thicknesses between echo top products and constant temperature altitudes (e.g., thickness between the 50 dB*Z* echo top altitude and the 0°C (273K) altitude). Useful for lightning initiation and hail diagnosis. The MRMS framework allows for different products at any reflectivity and temperature values.
CG LTG Probability	**Cloud-to-Ground Lightning Probability** – integrates lightning, 3D radar, and thermodynamic model data to nowcast probability of cloud-to-ground lightning on a 2D grid for the next 0-30 minutes.