OPERATIONAL ASSESSMENT OF PRE-DEPLOYMENT WSR-88D DUAL POLARIZATION DATA

Prepared By The

Applications Branch
Radar Operations Center
Norman, Oklahoma

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Executive Summary

An Operational Assessment of Pre-Deployment WSR-88D Dual Polarization (DP) data was held from the 17th - 19th of August, 2010. The primary objective of the assessment was to have field forecasters assess the potential effectiveness of applying DP data to forecasting and warning operations. The assessment was jointly conducted by the Radar Operations Center (ROC) Applications Branch and the Warning Decision Training Branch (WDTB) in the WDTB Training Laboratory at the National Weather Center in Norman, OK. A group of 20 forecasters, most with extensive radar expertise, took part in the assessment. Most of the group was composed of National Weather Service field forecasters but two representatives from the Air Force also participated. Each participant took part in preliminary DP training prior to attending the assessment. They also completed a pre-assessment survey to show how they rated the effectiveness of the legacy WSR-88D in their winter weather, flash flood, severe convection (e.g., hail and strong winds) and tornado warning operations.

On the 1st day of the assessment, we provided training on basic DP concepts, the key DP base variable data and derived products and forecasting applications integrating all available DP data. We emphasize that this training is not sufficient to develop forecaster expertise but provides familiarization with the use of DP data and its benefits. On the 2nd and part of the 3rd day, forecasters reviewed four DP case studies representing key forecasting and warning challenges faced by forecasters: winter weather, flash floods, severe convection, and tornadoes. Using detailed job sheets and help from Subject Matter Experts forecasters reviewed these cases to assess the potential of using DP data during these types of weather events. After each case study, forecasters provided feedback on the potential of using DP data for their operations and on the challenges they foresee in transitioning the new capabilities into their office operations.

At the end of the assessment, forecasters took a post-assessment survey with questions very similar to the pre-assessment survey. The key difference was that in the former survey forecasters were asked to rate, based upon what they learned during the assessment about DP data, the potential effectiveness of the DP WSR-88D radar in supporting forecasting and warning operations during winter weather, flash flood, severe convection and tornado events. Changes from the pre- to the post-survey ratings allowed us to gain a measure of whether forecasters believed DP data could potentially increase, decrease or cause no change to the WSR-88D's effectiveness. More importantly, forecasters were given the opportunity to provide comments to each of the survey questions. To support our results, we analyzed the post-assessment comments to determine if they were positive, negative or neutral. A ***positive*** remark indicated forecasters thought DP data could improve their capabilities. A ***negative*** comment indicated a forecaster believed DP data could detract from their capabilities. A ***neutral*** comment clearly indicated forecasters believed that the addition of DP data neither improved nor detracted from their capabilities. The pre and post assessment rating averages for each of the key forecasting and warning operations are shown in figure 1.

The largest difference in what the forecasters foresee as an improvement in what DP will bring to the WSR-88D is with respect to Winter Weather events. Out of 29 comments, nearly 76% were positive, 21% were considered neutral and one was negative. Positive comments focused on the use of DP data 1) to explicitly determine the location of the melting layer, 2) to determine the precipitation type during winter and delineate where rain/snow transition lines likely exist, particularly in areas where spotters or surface observations are sparse, and 3) to potentially bring a higher degree of confidence in short term forecasting during winter events.

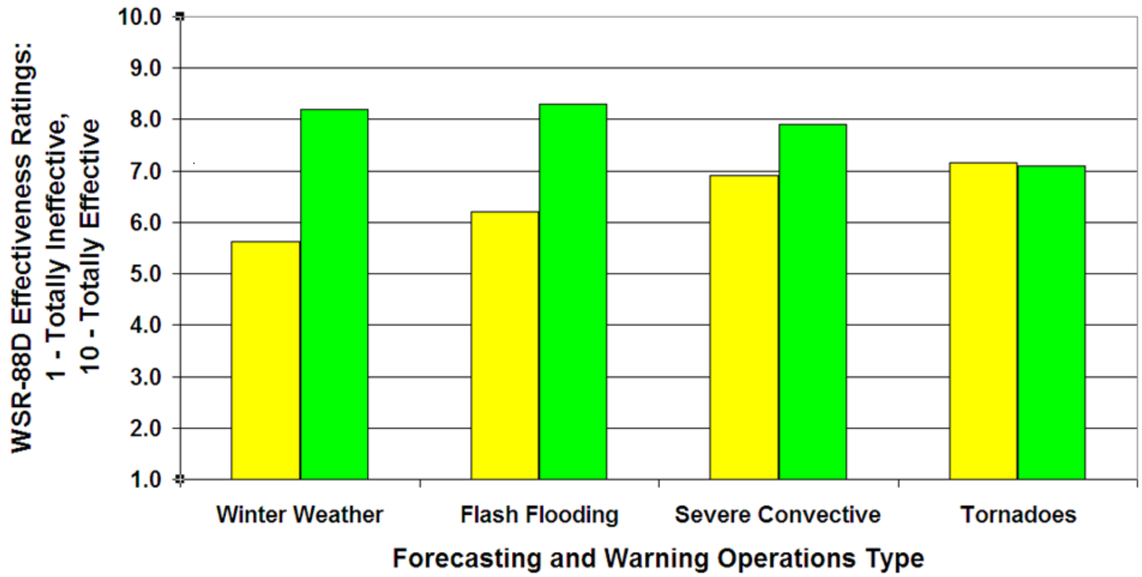

Figure 1: Average forecaster ratings for the effectiveness of the current (yellow) and the coming DP (green) WSR-88D during key forecasting and warning operations events.

Forecasters also foresee DP increasing the WSR-88D's effectiveness during Flash Flood forecasting and warning operations with nearly 80% of the comments positive. Nearly half of the positive comments specifically mentioned the utility of the DP base variable products to target areas with the heaviest rain rates. Three (out of 25) comments were negative and focused on some of the DP Quantitative Precipitation Estimation (QPE) limitations discussed during the assessment.

Forecasters foresee DP increasing the WSR-88D's effectiveness during Severe Convection although the increase is of a lower magnitude than that recorded for Winter Weather and Flash Flood operations. An examination of the comments reveals why. Forecasters noted the need to discern between non-severe and severe hail size: 1" or greater for NWS, greater than ½ inch for the Army and greater than ¾ inch for the Air Force. Currently, there is no algorithm using DP data that is sophisticated enough to provide this information. Yet this information is very important when considering whether to issue warnings for marginally severe storms. Additionally, they did not see DP data adding value to the prediction or detection of damaging winds. Nonetheless, forecasters noted that DP data 1) increased their awareness of where hail was located within storms, 2) helped them distinguish whether or not hail is of extreme size (> 2 inches) and 3) helped them target storms with strengthening updrafts, hence needing closer monitoring. Of the 23 comments, 65% were positive and 35% were neutral.

Forecasters did not believe DP would appreciably change the WSR-88D's effectiveness in tornado warning operations, at least in terms of increasing tornado lead time. Again, an analysis of the comments provides an explanation. Forecasters noted that DP would not add any value over what is currently available in the legacy WSR-88D base products for issuing a tornado warning. However, forecasters did note the potential for DP data confirming the presence of a damaging tornado for storms within 40 – 50 nm of the radar, a great asset at night or in spotter-sparse regions. Forecasters noted this would 1) enhance their situational awareness, 2) provide a way to communicate the tornado threat more effectively via follow-up severe weather statements and 3) help in tornado track analysis for damage surveys. Of the 29 comments provided, 59% were positive, 38% were neutral and one was negative. The one negative comment was a concern about the potential loss of velocity data due to the inherent sensitivity loss associated with the DP hardware upgrade.

At the end of the assessment, each forecaster wrote a summary that addressed what they believed were the top DP benefits, the top challenges of implementing DP into their office operations and what they believed are the top research areas needed to improve DP data. By far, the top DP benefits noted were 1) the improved ability to pinpoint heavy rain along with the potential for receiving better rain estimates through DP QPE, 2) the improved ability to interrogate severe convection, e.g., discerning hail, updraft strength and tornado debris locations, and 3) an improved capability to discern precipitation type during winter weather events. The top challenges mentioned were the 1) need for DP training, 2) developing expertise within the office and 3) the perceived workload increase with the addition of the new DP data. Finally, the top research areas noted were 1) work in refining the DP QPE estimates and 2) developing a method for DP to explicitly discern hail size.

In view of the data examined, the Operational Assessment Team came to the following conclusions:

1. **The Assessment enabled forecasters to foresee DP increasing the WSR-88D's effectiveness during Winter Weather, Flash Flood, and Severe Convection forecasting and warning operations. For tornado warning operations, forecasters focused more on the potential for DP to confirm the presence of damaging tornadoes, which in turn will improve their situational awareness and the ability to convey to the public the threat in follow-up severe weather statements. However, they don't anticipate DP data will improve their ability to issue tornado warnings with increased lead-times.**

2. **Forecaster feedback indicates the top challenges of implementing DP into office operations are the need for a robust training program, the need to**

develop forecaster expertise and a method for mitigating the increased workload perceived with the new DP data.

3. **Forecasters believe the top research areas to improve DP data are continuing the development on the DP QPE algorithms and to develop the ability to distinguish hail of different sizes.**

Operational Assessment Team Members

Stephen Cocks	ROC	Assessment Director
Paul Schlatter	WDTB	Assessment Execution Mgr. & DP SME
Richard Murnan	ROC	Data Evaluation Mgr. & Test SME
Joe Chrisman	ROC	Test and Radar SME
Don Burgess	OU/CIMMS	DP & Radar SME
Kevin Manross	OU/CIMMS	DP SME
C. VanDenBroeke	OU/CIMMS	DP SME
Clark Payne	OU/CIMMS	DP SME
Edward Mahoney	WDTB	Training, Test & Radar SME
Elizabeth Quoetone	WDTB	Training, Test & Radar SME
Jami Boettcher	WDTB	DP & Training SME

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1. Introduction

An Operational Assessment of Pre-Deployment WSR-88D Dual Polarization (DP) data was held from the 17th - 19th of August, 2010. The primary objective was to have operational field forecasters assess the potential effectiveness of applying DP data to forecasting and warning operations. The request for an operational assessment originated from a Subject Matter Expert (SME) panel that had convened in December 2009 to consider the operational impacts of a 4 dB or higher sensitivity loss on the WSR-88D fleet (ROC Technical Report I, 2010). For clarification, we define ***Sensitivity*** as a measure of how well a radar can detect meteorological targets via signal processing the reflected energy for any given range. In general, the more sensitive a radar, the better its ability to detect weaker meteorological features such as outflow boundaries and very light rain/drizzle or snow. Therefore, ***Sensitivity Loss*** is a loss in the radars ability to detect these weaker features at any given range. When a radar undergoes a major hardware change, it is typically compared to a "benchmark" or test radar. It is during these comparisons that ***Sensitivity Differences*** become clear.

During the late summer and fall of 2009, comparisons between the KOUN DP prototype and the Radar Operation Center (ROC) test radar indicated a substantial sensitivity difference. Engineers and meteorologists expected a 3 dB loss in sensitivity due to the required splitting of power into a horizontal and vertical channels, a design requirement of the DP prototype. The sensitivity difference between the KOUN prototype and the ROC test radar was larger than expected. Hence, the SME panel was convened to further investigate this problem as well as estimate the operational impacts of a higher than expected sensitivity loss to the WSR-88D fleet due to the DP upgrade. The panel viewed data exhibiting a wide range of meteorological signatures, both at legacy sensitivity and several levels of a simulated sensitivity loss. As part of the SME panel findings, a recommendation was made to conduct an operational assessment, using field forecasters, to resolve whether a greater than 4 dB sensitivity loss would significantly impact forecasting and warning operations.

During the winter of 2009-10, the KOUN DP prototype radar's receiver was re-designed with new, more robust hardware installed. As a consequence of the re-design, the KOUN DP prototype radar's sensitivity was increased. However, continued concerns about the remaining sensitivity difference between the KOUN DP prototype and ROC's test radar culminated in the convening of a 2nd SME panel in March 2010 (ROC Technical Report II, 2010). During this panel, the concerns about the sensitivity difference between the DP Prototype and the ROC's test radar were resolved. In particular, a ROC engineering analysis provided to the SME panel concluded the final sensitivity loss associated with the DP hardware upgrade on any WSR-88D will vary between 3.5 to 4 dB, very close to the expected 3 dB sensitivity loss (ROC Technical Report III, 2010). However, as part of the SME Panel's findings and conclusions, the panel recommended *"shifting the focus of the Operational Assessment more towards a Training, Technology Exposure and Transition Exercise."* This recommendation was implemented in the operational assessment plan.

The assessment was jointly conducted by the Radar Operations Center (ROC) Applications Branch and the Warning Decision Training Branch (WDTB) in the WDTB Training Laboratory at the National Weather Center in Norman, OK. A group of 20 forecasters, 18 from the National Weather Service (NWS) and 2 from the Air Force (AF), all with extensive radar expertise, took part in the assessment. This report documents the methodology used by the Operational Assessment Team (OAT) to conduct the operational assessment. This report also examines the results from the assessment and the conclusions reached.

2. OPERATIONAL ASSESSMENT METHODOLOGY

2.1 Operational Assessment Goals & Resources

To meet the focus specified by the second SME Panel recommendation, the following objectives were defined for the operational assessment:

<u>Primary Goal</u>: *Field forecasters assess the potential effectiveness of applying Dual Polarization (DP) data to forecasting and warning operations*

<u>Secondary Goals</u>:

1) *To train and expose forecasters to the use of DP data*

2) Gain forecaster feedback on how they expect to transition DP data into their office's forecast and warning operations

3) Expose forecasters to key DP performance considerations (e.g. DP associated sensitivity loss, radar attenuation effects on DP Data, etc.)

The ROC Applications Branch was tasked to plan and organize the operational assessment but we, ROC staff members, quickly recognized the need to tap into the experience and expertise available in the WDTB to develop a plan and organize the resources needed to execute it. WDTB was a natural choice as they regularly provide training courses, such as the Distance Learning Operations Course and the Advance Warning Operations Course, to National Weather Service forecasters. Their courses are conducted using a variety of training materials and hands-on-learning via the use of case study reviews or simulations. To support their mission, WDTB has a 24-workstation AWIPS laboratory where students have the opportunity to test out their new knowledge by reviewing case studies or participating in forecasting simulations. During a simulation, data is provided to a student at a real time pace and the student must make forecasting and warning decisions. This laboratory was the perfect place to hold portions of the operational assessment, while the training and classroom instruction took place in a spare classroom in the National Weather Center. Figures 1 and 2 show the AWIPS laboratory and the classroom used for the training during the assessment.

Next, we coordinated with the NWS Regional Science Directors to select participants from across the National Weather Service. We asked for four participants each from the Western, Central, Southern and Eastern regions and one participant from the Pacific and Alaskan regions. We invited a forecaster from one of the Center Weather Service Units (CWSU) that support the Federal Aviation Administration operations and a forecaster from the United States Air Force (AF). Unfortunately, the Pacific region and the CWSU participants had to bow out due to other commitments, therefore an additional forecaster from the AF and the NWS Southern Region were brought in to replace them. The result was 20 forecasters, whose group picture is shown in figure 3.

Figure 1: WDTB's AWIPS laboratory during the operational assessment.

2.2 Data Collection and Preparation

For the purpose of creating DP data cases for the assessment, Level II WSR-88D data from the KOUN DP prototype were collected, played-back and ingested into AWIPS. To support the DP data cases and to promote forecaster discussions, upper air and surface maps along with sounding data were downloaded from a host of Internet web-sites. These data were used to create briefings that the forecasters could use to gain situational awareness of the type of environmental conditions expected for a DP data case. We also downloaded preliminary storm reports from the Storm Prediction Center, Norman WFO and the CoCoRahs web-sites to provide ground truth information for each DP data case. Finally, Level II WSR-88D data were collected from a number of sites across the U.S. to be used as part of a sensitivity demonstration during the assessment.

2.3 Test Methodology

We formed a working group comprised of ROC Applications and WDTB staff members to develop the plan needed to conduct the operational assessment. In order to meet the goals of the assessment we organized it into four phases:

Figure 2: Photo of the classroom used during training portions of the operational assessment.

PHASE I: Train and expose forecasters to the fundamentals of DP, the key DP base variable and derived products and how they could be applied in forecasting and warning operations

PHASE II: Forecasters assess DP data

PHASE III: Train forecasters on key DP performance characteristics

PHASE IV: Forecasters write a summary, providing feedback on what they believe are the top DP key benefits, the top challenges their office will face to integrate DP data into their operations, and what DP research areas they believe are most important to furthering the improvement of the DP products and algorithms.

As temporary duty funds were limited, we restricted the assessment to three days. PHASE I, the training phase, was conducted via pre-assessment training and on the 1st day of the assessment. PHASE II, the assessment phase, occurred on the 2nd and part of the 3rd day of the assessment, followed by PHASE III and PHASE IV, also on the 3rd day. To assist with the execution of the operational assessment, a team of experts was assembled to provide insight into the use and interpretation of DP data as well as answer

Figure 3: The forecaster participants chosen for the Dual Polarization Operational Assessment. From left to right, and starting from the back: Jason Dunn (WFO Ft Worth, TX), Bob Fischer (WFO Fairbanks, Alaska), Robert Darby (WFO Tulsa), Justin Lane (WFO Greenville, SC), Bill Hibbert (WFO Buffalo, NY), Brian Carcione (WFO Huntsville, AL), Chris Rasmussen (WFO Tucson, AZ), Mark Burger (WFO Eureka, CA), Ken Cook (WFO Wichita, KS), Robert Handel (WFO Atlanta, GA), Thomas Herb (26th Operational Weather Squadron), Jerilyn Billings (WFO Wichita, KS and one of the OAT members), Kyle Weisser (WFO Fargo, SD), Ken Kostura (WFO Blacksburg, VA), Rod Donavan (WFO Des Moines, IA), Doug Green (WFO Phoenix, AZ), Dan Miller (WFO Minneapolis), Brandon Vincent (WFO Raleigh, NC), Dean Hazen (WFO Pocatello, ID), MSgt Jerome Adams (AF Weather Agency), Eric Howieson (Southern Region WSR-88D Focal Point) .

forecaster questions. We looked for key individuals within the WDTB, the ROC and National Severe Storms Laboratory (NSSL) who were Subject Matter Experts (SMEs) in weather radar, operational testing, meteorological training, DP data interpretation and applications. This group of individuals, the Operational Assessment Team (OAT), finalized our plan, executed the event and helped examine and summarize the results. The OAT members are listed in Table 1.

Table 1: A listing of the Operational Assessment Team members used to conduct the Operational Assessment.

NAME	ORGANIZATION	POSITION
Stephen Cocks	ROC	Assessment Director
Paul Schlatter	WDTB	Test Execution Manager & DP SME
Rich Murnan	ROC	Data Evaluation Manager & Test SME
Don Burgess	OU/CIMMS	Weather Radar & DP SME
Joe Chrisman	ROC	Weather Radar & Test SME
Ed Mahoney	WDTB	Test & Training SME
Liz Quoetone	WDTB	Test & Training SME
Jami Boettcher	WDTB	Training & SP SME
Clark Payne	OU/CIMMS	DP SME
Cynthia VanDenBroeke	OU CIMMS	DP SME & AWIPS Expert
Kevin Manross	OU/CIMMS	DP SME
Jerilyn Billings	WFO Wichita	Field Forecaster and AWIPS Expert

2.3.1 Training Requirements

Critical to meeting the primary goal of the assessment was training forecasters, some of whom had little experience with DP data, to a level sufficient to consider DP data's utility in forecasting and warning operations. However, as travel funds were limited, it was clear that a week's worth of training would not be possible. To mitigate this, we required forecaster participants to take part in DP training prior to the assessment. For National Weather Service personnel, this consisted of an eight hour training course, "Dual Pol Primer on the Weather Event Simulator (WES)," which was released by WDTB in December of 2009. As the Air Force forecasters do not have access to a WES, a proxy of this training was provided via existing WDTB DP education modules available on the WDTB web-site. This way, forecasters arrived at the assessment with an introduction to the fundamental concepts of DP.

The training provided on the 1st day of the operational assessment was designed to reinforce, as well as, build upon the training they completed prior to their arrival. Presented were the fundamental DP concepts, the key DP base variable data and derived products, and how to practically apply the information during forecast operations. A section was provided that taught forecasters how to pull together the various DP products in order make forecasting decisions. Throughout the training, we used quizzes designed to help forecasters retain the key concepts needed later to apply DP data to weather event case studies. Once this instruction was completed, a hands-on demonstration was provided to forecasters via moving them into the WDTB laboratory to participate in an instructor-led review of a DP case study. This was to allow forecasters an opportunity to use, in a practical way, the DP data prior to the assessment phase of the operational assessment.

Table 2: A listing of the training course provided prior to and during the 1st day of the operational assessment.

COURSE WORK	TIME ALLOTTED
Dual Pol Primer on the WES ***(Pre-assessment only)***	8 hours
Dual Pol on-line Training Modules ***(Pre-assessment only for AF)***	2 hours
Basic Principles of Dual Polarization	15 minutes
Correlation Coefficient	30 minutes
Differential Reflectivity	45 minutes
Specific Differential Phase	45 minutes
Hydrometeor Classification and Melting Layer Detection Algorithms	40 minutes
DP Quantitative Precipitation Estimate Products	30 minutes
DP Forecasting Applications for Snow, Rain, Melting Layer and Heavy Rain	40 minutes
DP Forecasting Applications for Hail, Strong Updraft, and Tornado Debris Signatures	1 hour
Putting it all together: AWIPS DP Demo with 16 May OKC hailstorm, 19 May Central Oklahoma Supercells & 04 July Heavy Rain event	1 hour 15 minutes

We emphasize that the training provided was not sufficient to develop forecaster expertise. Instead, it provided familiarization with the DP data and knowledge of how to apply it during forecasting and warning operations. Therefore, when forecasters began the assessment phase, e.g. PHASE II, they would have enough knowledge to consider the utility of using DP data. A complete listing of the training provided can be seen in Table 2.

2.3.2 Test Execution Methodology

In order to have forecasters assess DP data we needed to create a test methodology. There were two ways to do this: 1) have forecasters participate in case study reviews or 2) have forecasters participate in forecast simulations. In a simulation, radar data is provided in real-time to a forecaster and he or she is required to make forecasting and warning decisions based upon his or her analysis. The advantage of a forecast simulation is it allows a more quantitative measurement of whether a particular forecasting technique or, in this case new type of radar data, actually improves forecaster performance or increases warning skill.

However, forecast simulations in the context of this assessment were not an option because 1) most forecaster participants only had limited knowledge of DP data, 2) a more intensive and longer training regiment would be required in order for forecasters to participate in a simulation, 3) a significant period of time is needed to allow forecasters to assimilate new information then intelligently make forecasting and warning decisions during a simulation and 4) the deployment version of the DP system was not available.

With regards to points 2) and 3), WDTB estimated that 3 weeks of training followed by a couple of months of assimilating the knowledge and using the data would be required before a forecaster could realistically be ready to participate in a simulation and provide meaningful results. In regards to point 4), changes were still occurring as the DP prototype was undergoing systems test and the precipitation algorithms were and still are being worked upon.

Given these limitations, case study reviews were used and were defined as the following: forecasters review radar data of a weather event at a series of specific times while working through job sheets. The job sheets were written such that forecasters were required to execute tasks requiring them to use DP data in conjunction with legacy products and gauge the potential utility of the new DP data and what it could add to the forecast process.

For each case study reviewed the OAT provided a pre-briefing, a forecaster analysis period, a post-briefing and a forecaster feedback period. The pre-brief, conducted prior to each case study review and lasting 5-10 minutes, was composed of a discussion, using key upper air and surface charts, of the atmospheric conditions leading up to the weather event to be reviewed. The analysis period, lasting anywhere from 40 to 120 minutes and was case study dependent, allowed forecasters to examine radar data and work through their job sheets. During the analysis period, OAT members were available to answer forecaster questions. OAT members ensured that forecasters understood the job sheet questions, were able to find the relevant products, and got answers to any DP interpretation questions. The post-brief, lasting anywhere from 10 to 40 minutes and also case study dependent, consisted of a short data review highlighting the key storm events and a review of the job sheets. During the post brief, there was a question/answer session between forecasters and the OAT members. Once completed, forecasters provided feedback via an online survey the team developed. Details on the surveys and the philosophy behind them will be presented shortly.

The weather events the OAT chose for case study reviews were related to mission-critical forecasting and warning operation areas: winter weather, flash floods, tornadoes and severe convection (severe wind and hail alone). Obviously, there are other important weather event operations such as those associated with Fire and Marine forecasting events. However, the KOUN DP prototype is located in Central Oklahoma, far from the coast, and we did not have any notable scrub fires this past year. The four events chosen are summarized in Table 3. Level II radar data was collected from the KOUN DP prototype and passed to WDTB to replay via a Radar Product Generator software package and converted into product files that could be used by AWIPS. To go along with each storm event, ROC applications personnel collected the key synoptic charts and storm reports needed to put together the Pre and Post briefings for each case study.

Table 3: A list of the case studies used during the case study review phase of the operational assessment.

CASE STUDY	TIME ALLOTTED
I. Two DP Winter Weather Events over Northern and Central Oklahoma, 26 February and 20 March, 2010	2 hrs 10 minutes
II. 14 June 2010 Flash Flood Event in Oklahoma City, OK	2 hrs 10 minutes
III. Central Oklahoma Tornado Outbreak and Examples of Very Large Hail, 10 May 2010	3 hrs 20 minutes
IV. Bow Echo over Northern Oklahoma, 19 May 2010	1 hr 45 minutes

2.3.3 Sensitivity Demonstration

A portion of the third day of the assessment was used to discuss key DP performance characteristics. As part of this briefing, a demonstration was given to illustrate to forecasters the affect the DP associated 4 dB sensitivity loss could have on their ability to discern meteorological signatures. This was the maximum sensitivity loss expected, upon Dual Polarization upgrade, at each NEXRAD radar as deduced by a ROC engineering analysis (ROC Technical Report III, 2010). Using the same method as in the two SME Panels, we provided a sensitivity demonstration for the operational assessment. We took radar data from a variety of locations and demonstrated the affect a 4 dB sensitivity loss could have on identifying key weather signatures.

To support this demonstration, we selected a variety of weather cases to use for this demonstration and a list of them can be found in table 4 below. These selected cases exhibited weather radar signatures from many locales across the U.S. This included examples of mesocyclones, strong and weak outflow boundaries, wildfire smoke plumes, snow bands, and freezing drizzle. To create the demonstration, we collected Level II radar data and reduced the sensitivity by 4 dB via a methodology very similar to a NSSL report on the affects of a DP sensitivity loss (Scharfenberg et al. 2005). Details of this methodology can be found in Appendix A. Figure 4 shows examples of both the legacy and the 4 dB sensitivity reduced reflectivity data that was viewed by forecasters during the assessment. Figure 5 shows an example of a Velocity Azimuth Display (VAD) Wind Profile generated with legacy and 4 dB sensitivity reduced. As with Scharfenburg et. al. 2005, about 5-10% of the data, mainly the higher level wind barbs, were lost when the sensitivity was reduced in this sample. Overall, the 4 dB sensitivity change affected the precipitation algorithms very little. In one case, there were a few *additional* pixels in the reduced image when compared to the legacy image. These artifacts were investigated and found to be due to the missed identification of clutter by the Radar Echo Classifier algorithm (see Figure 6).

Table 4: A list of the case studies used for the Sensitivity Demonstration during the operational assessment.

CASE STUDIES USED FOR THE SENSITIVITY DEMONSTRATION	KEY METEOROLOGICAL FEATURES
I. Hurricane Ike Landfall near Houston, Texas, 13 September 2008	Eyewall, Rainbands
II. Popcorn Convection near Eglin AFB, Florida, 07 August 2008	Numerous Convective Outflows varying from near the radar to ~100km away
III. Wildfires and Severe Thunderstorms in Central Oklahoma, 09 April 2009	Supercells ahead of the dryline, along; behind dryline, numerous plumes of smoke
IV. Bow Echo over Western and Central Oklahoma, 16 May 2009	Squall Line with associated outflow boundaries
V. Marginal Lake Effect Snow Event Buffalo, New York, 04 December 2009	Weak reflectivity echoes associated with light snow at a distance from the radar
VI. Portion of Record East Coast Snowstorm, 05 February 2010	Meso-scale snow band structures at varying distance from the radar
VII. Dryline near Dodge City, Kansas, 05 June 2008	Dryline and initiation of convection along it
VIII. Arctic air passage through Wichita, Kansas, 03 January 2009	Very light freezing drizzle
VIIII. Supercell, EF3 Tornado near Windsor, Colorado, 22 May 2008	Warm front fine line, evolution of mesocyclone
X. Wildfires near Los Angeles, California, 27 August 2009	Smoke Plumes

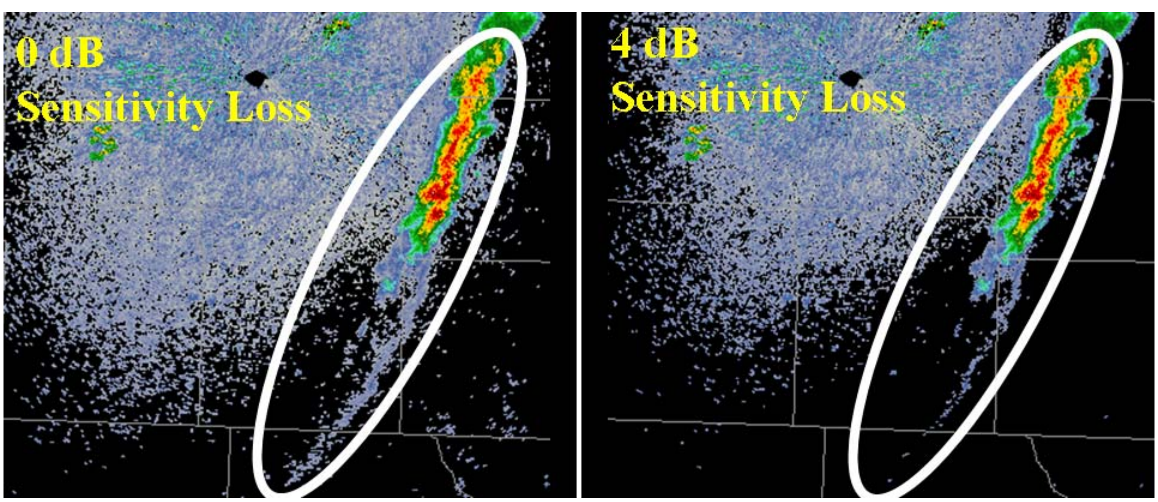

Figure 4: Legacy (left) and 4 dB reduced sensitivity (right) WSR-88D Level II data for convection initiating along a dry line near Dodge City, KS.

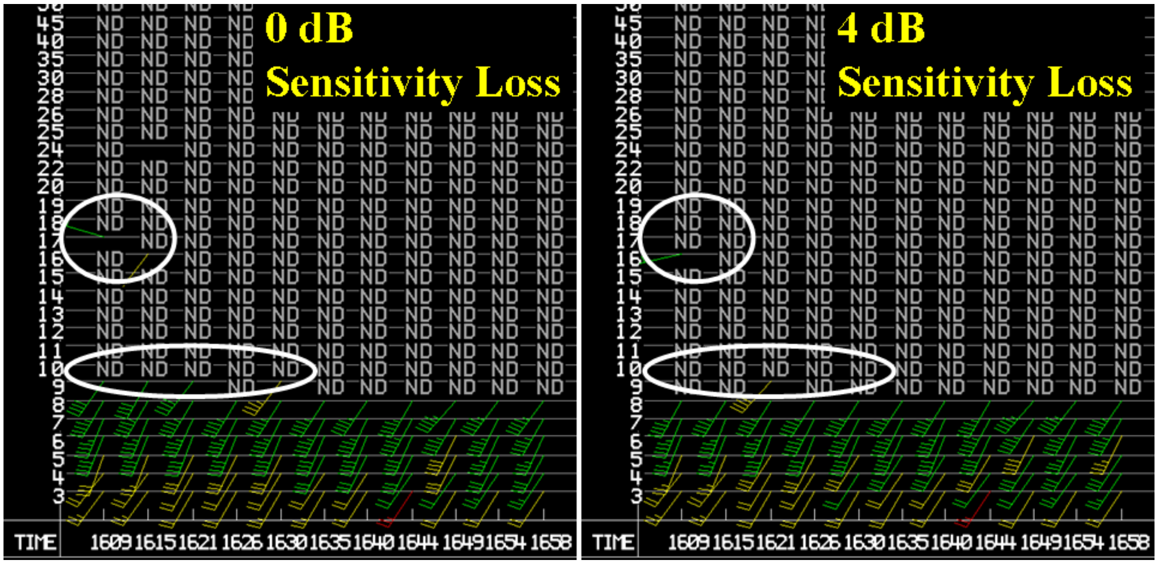

Figure 5: Legacy (left) and 4 dB reduced sensitivity (right) WSR-88D VAD Wind Profile data near Dodge City, KS. White circles and ovals depict the differences between the two products, mainly a loss of of some data at 9000 feet and 16000 feet. .

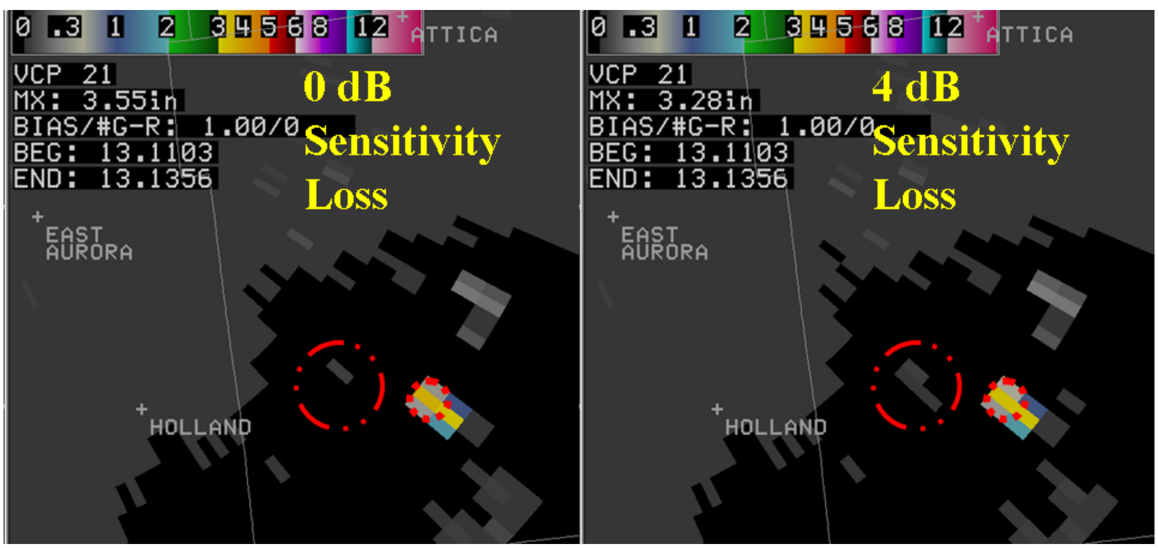

Figure 6: Legacy (left) and 4 dB reduced sensitivity (right) WSR-88D Storm Total Precipitation Product for synoptic scale light snow near Buffalo, NY. Red circles outline regions where slight increases of STP occurred in the 4 db reduced data, an artifact caused by the way the various NEXRAD algorithms treat clutter.

2.3.4 Assessment Surveys & Forecaster Summaries

We used a series of surveys to solicit feedback from the forecasters prior to, during and after the assessment. The purpose of the pre-assessment survey was to determine how forecasters view the effectiveness of the legacy WSR-88D radar. Specifically, we asked forecasters to rate the overall effectiveness of the WSR-88D in supporting their interrogation process for a Severe Convection (e.g., strong winds and large hail), Tornado, Winter Weather, Flash Flood threat. Forecasters rated the WSR-88D on a 0 – 10 scale, where '0' represented a threat that is not applicable to the forecaster because of its rarity, '1' represented the radar is totally ineffective, and '10' represented the radar is totally effective for the given threat. Additionally, for each threat category, the forecasters were given the option to explain why they gave a particular rating in a comments section. This information gave the OAT members a good understanding of how the forecasters rated the effectiveness of the WSR-88D prior to coming to the assessment.

At the end of the operational assessment, forecasters completed a post-assessment survey, with questions very similar to the pre-assessment survey. However, in this survey we asked forecasters to rate the potential effectiveness of the Dual Pol WSR-88D based upon what they experienced and learned during the assessment. As in the pre-assessment survey, forecasters were asked to provide explanations for their ratings. An example of the questions asked in the Pre- and Post-Assessment Surveys can be found in Appendices B & C.

We used the results from both the pre and post-assessment surveys, specifically looking for the change in the ratings for a given threat, to obtain a measure of whether forecasters could foresee an increase or decrease in the WSR-88D's effectiveness due to the DP upgrade. We also examined the post-assessment comments for recurring themes to gain an understanding of why the forecasters gave the DP WSR-88D a particular rating. Further, in order to gain a quantified understanding of how strongly the forecasters, as a group, felt about the DP data we classified the post-assessment survey comments as positive, negative and neutral. A ***positive*** comment clearly indicated forecasters thought DP data could improve their capabilities. An example of a positive comment would be the *"capability to determine melting layer will…..improve short term forecasting."* A ***negative*** comment indicated a forecaster believed DP data could detract from their capabilities. An example of a negative comment would be the following: *"…if the DP QPE products cannot be shown to be a major improvement over the legacy products……. forecasters may view the DP products as "one more damn thing I have to look at during hydro events…"* A neutral comment clearly indicated forecasters believed that the addition of DP data neither improved nor detracted from their capabilities. An example of a neutral comment would be the following: *"The use of dual-pol variables did not significantly increase my ability to detect tornadoes."* This comment is neutral because the DP data did not detract from the forecaster's capability to warn on tornadoes using legacy reflectivity and velocity data. Using these analysis techniques, the OAT developed a good understanding of why a particular forecaster gave the DP WSR-88D a particular rating.

We also asked forecasters to provide feedback about the utility of the WSR-88D in supporting their Aviation, Fire-weather, Marine and High Impact Event Forecasting Decisions. In the pre-assessment survey, we asked forecasters to rate the effectiveness of the WSR-88D in these key areas and to provide an explanation for the rating. However, during the operational assessment, it was not possible to include case studies that would relate directly to Aviation, Fire Weather, Marine or High Impact forecasting decisions.

Therefore, in the Post-Assessment Survey, we only asked forecasters to mention if they foresee any DP applications that could support their Aviation, Fire-weather, Marine and High Impact Event Forecasting Decisions. That way we could document any promising ideas, evaluate them and "spread the word" if useful.

We also solicited forecaster feedback immediately after the completion of each case study review. The survey questions were used to determine if DP data enhanced or detracted from the forecaster's process of building their conceptual model for a given threat. We also asked how forecasters believed the DP data either enhanced or detracted from their understanding and which DP products were responsible. Additionally, we asked forecasters to share any strategies they developed to better manage the data workload. An example of one of the case study surveys is found in Appendix D.

These surveys helped us focus on what were the most useful products, potential problems forecasters foresee in using the DP data and the key challenges for their offices once the DP upgrade occurs. It likely helped forecasters to focus on the key DP advantages and perceived challenges and write them down. Because of this, we provided forecasters their results from the survey questions prior to the final Post-Assessment Survey and their assessment summaries so they could use them as a reference of how they graded the earlier case studies.

As mentioned earlier, the OAT asked forecasters to write an Assessment Summary that answered the following questions:

- ***In light of what you have learned this past week, what are the top three benefits that you believe Dual Polarization will provide once it is initially deployed and why?***

- ***What do you perceive will be the biggest challenges in implementing the Dual Polarization suite of products into your office operations?***

- ***After Dual Polarization is deployed, what are the top three areas that you believe future research and development on the Dual Polarization WSR-88D radar are most needed and why?***

- ***With reference to the goals of this assessment, was it conducted to your satisfaction? Please explain why or why not.***

In short, the forecaster Assessment Summary was meant to answer key questions that the Post-Assessment Survey would not cover completely. It asked the forecaster to clearly list the top benefits they perceived, list in detail the top challenges they believed they will face when the DP upgrade comes to them and what DP areas they considered needed the most research and development. Finally, the last question was used to find out if forecasters believed the assessment was relevant for them. We asked the forecasters to limit their Assessment Summaries to 5 pages or less in order to encourage them to focus on the questions we needed answered.

2.3.5 Assessment Limitations

Despite the work put into the plan discussed above, there were some distinct limitations to the operational assessment. First, the assessment utilized pre-deployment WSR-88D DP data; DP products were not in their “final state” when forecasters viewed them. There was no way to get around this, especially since the time of this writing there is still some calibration work occurring on the radar and DP Quantitative Precipitation Estimate (QPE) algorithms are still being worked upon. Another limitation was that the DP case study reviews featured data only from Oklahoma. There was no way around this limitation as the KOUN DP WSR-88dD prototype is exclusively located in Norman, Oklahoma. We expect DP algorithm performance to vary by geographical area. We were also limited to putting together an assessment over a three day period due to funding. The travel costs for this assessment were around $42,000. A more lengthy assessment would have taken even more travel funds and appreciably more man-hours to execute.

Training provided prior to and during the assessment was also limited in that it did not make the forecasters DP experts. Creating true expertise in the use of DP data is not just a function of the amount of training received but also requires the repeated exposure and practice to assimilate the data into both interrogation methodology and analysis. Instead, as noted earlier, the training was intended to familiarize forecasters with DP data and its capabilities so they would be able to participate in the assessment. Finally, the Air Force forecasters taking part in the assessment did not view the radar data through the Open Principal User Processer (OPUP) display as one was not available within the WDTB laboratory. Instead, each AF forecaster was paired with an OAT member who guided them, via AWIPS, through Case Study Reviews. The AF forecasters could ask questions and have the OAT member get them the products they wanted to view.

3. OPERATIONAL ASSESSMENT RESULTS

We conducted the operational assessment on the 17th - 19th August 2010. The surveys and comments from the assessment were collected and analyzed. This section summarizes the results from the pre- and post-assessment surveys and the results from the forecaster assessment summaries.

3.1 Pre-and Post-Assessment Survey Results

As mentioned in section 2.3.4, forecasters rated the effectiveness of the WSR-88D prior to the assessment, and, again, after the assessment. Both surveys asked the same questions except for one key difference. Forecasters answered post-assessment survey questions in light of what they learned, during the assessment, about the capabilities and limitations of DP data. We looked at the rating differences between the pre- and post-assessment survey to determine if forecasters foresee that DP data could impact the effectiveness of the WSR-88D radar. We classified the Post-Assessment Survey comments as positive, negative and neutral using the criteria discussed in section 2.3.4, and we examined the comments for recurring themes. Comments such as “could discern precipitation type” provided insight to the reason why forecasters gave a particular rating.

As a start, we took the average ratings for each forecasting and warning operations type and these are shown in figure 7. Overall, the results show that forecasters foresee DP increasing the effectiveness of the WSR-88D in Winter Weather and Flash Flood warning operations, and, to a lesser extent, increase the effectiveness for Severe Thunderstorm warning operations. Forecasters did not foresee DP increasing the effectiveness of tornado warning operations, realizing that DP products would not provide an increase to initial tornado warning lead time. However, forecasters did state that DP data will give them better situational awareness during tornado operations. We will discuss the survey results in-depth in the following sections.

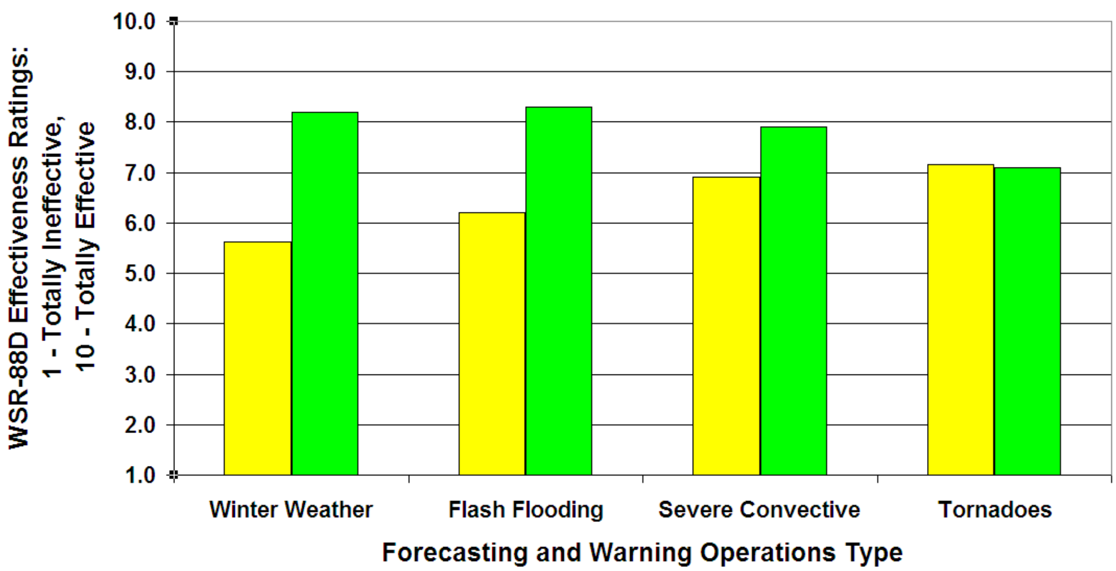

Figure 7: Average forecaster ratings for the effectiveness of the legacy (yellow) and the DP (green) WSR-88D during high impact forecasting and warning operations events.

3.1.1 Survey Results for Winter Weather Events
Forecasters foresee DP as having the greatest potential to improve effectiveness with Winter Weather events. The distribution of the forecaster effectiveness ratings for winter weather events for both the pre- and post-assessment surveys follows (see Figure 8).

Pre-Assessment: Prior to the assessment, there was a wide distribution in the ratings; an examination of the comments provides some insight into the varied scores. Pre-assessment comments mentioned the somewhat limited ability to identify precipitation type. For example:

"Tracking and evaluation of the evolution of lake effect snow bands is a primary use of the WSR-88D here in Buffalo for winter weather events. Determination of precipitation type during a winter weather event is always a problem, not easily addressed by WSR-88D products." ***RATING: 8***

'My experience with winter weather events and the 88D is somewhat limited...but the few that I have worked I would say that the radar is fairly effective in identifying different types of precipitation. Of course this is based on the forecaster's knowledge of echo identification and associated precipitation type." ***RATING: 7***

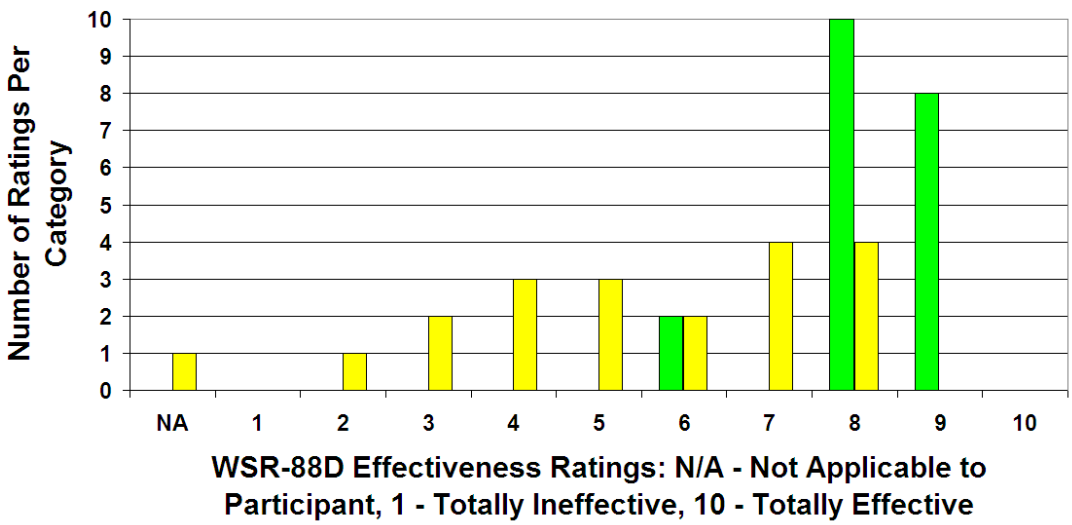

Figure 8: Distribution of the Pre (yellow) & Post (green) Assessment forecaster ratings for the effectiveness of the WSR-88D during winter weather events. Note the large spread in ratings in the pre-assessment changing to a tighter cluster in the post.

There were also comments that noted the WSR-88D's inability to truly distinguish between the various winter weather precipitation types. For example:

"Other than the 'bright band', which helps identify the melting layer, the WSR-88D is extremely ineffective at interrogating winter weather." ***RATING: 2***

"……In its current configuration, the 88D is simply not effective in providing much operational support during winter weather events, UNLESS there is no ambiguity

concerning precipitation type. This is a very rare occurrence for those of us in the inland southeast. Being able to assess varying precipitation types will render the 88D a much more useful tool to winter weather ops." ***RATING: 3***

Though not part of the DP upgrade, comments noted the lack of the WSR-88D's ability to scan below 0.5 degrees, a real limiting factor for radars located on elevated terrain, thus hindering the ability of the radar to detect precipitation in valleys, etc. For example:

"Coverage limitations can be a big problem for us. Radars are geographically spaced further apart out west and terrain can also hamper coverage. Single biggest limitation is lack of low level sampling (i.e. below 0.5 elevation slice). It's not unusual to get significant snow amounts without any detection due to the beam overshooting the precipitation........" ***RATING: 4***

"Our forecast area gets considerable snow during the winter. However, many of the higher impact areas are in narrow valleys where precipitation phase is very difficult to ascertain. Given the radar is located some distance from these valleys, the beam is always too high to be of much use in these events. For instance, a typical event may feature a "free air" snow level of 5,000 feet elevation, with rain below. But, often, cold air trapped in these valleys, located between 900 feet MSL and 2,900 feet MSL will experience snow." ***RATING: 4***

DP Capabilities During Winter Weather Operations: DP cannot solve the elevation and coverage issues since the scanning strategies and radar locations will not change, but it can be used to identify and differentiate between a variety precipitation types. Correlation Coefficient (CC) is the best discriminator for identifying the height of the melting level, important for aviation interests and for winter weather nowcasting. Additionally, one can use CC and differential reflectivity (ZDR) to discern between regions of rain, wet snow and dry snow. This makes it easier to locate and track the movement of rain/snow transition lines. With all radar products, DP or not, it is especially important to remember the height above the ground the radar is sampling because precipitation type can and often does change prior to reaching the ground. Nonetheless, these DP base variable products, with proper training, can give much more insight into winter precipitation type at the surface than the legacy WSR-88D.

Post Assessment: In the Post-Assessment survey, forecasters clearly saw DP increasing the effectiveness of the WSR-88D during winter weather events. Out of 29 comments, 76% were positive, 21% were neutral and one was negative. The negative comment is the following:

"Hopefully the loss of sensitivity at the lower db levels will not remove reflectivity in association with light freezing drizzle/light dry snow." ***RATING: 8***

Note that the negative comment was still associated with a rather high rating. The concern over the sensitivity loss due to the DP upgrade and its potential impact to the forecaster will be discussed in section 4. Some examples of positive comments are the following:

"…..This, along with hydro(-meteorology), is where DP should pay for itself. In its current configuration, the WSR- 88D is more of a background tool during winter precipitation events since the vast majority of our events in the interior Southeast involve mixed precipitation type. It is often the case that precipitation type remains largely a mystery to our forecasters until spotter reports of precipitation type are received. DP will infuse the now-casting and near-term forecasting of winter weather events with a boost of confidence" ***RATING: 8***

"Dual Pol radar will be most effective at winter weather analysis and precipitation type determination……..." ***RATING: 9***

"Winter weather is a common event in our area and our office has typically had issues with accurately assessing melting layers and areas of heavier precipitation. I think dual pol will add an entire new element to winter weather forecasting at the office, mainly by helping reinforce the underlying conceptual model forecasters are employing. While algorithms like HCA will still need to be used with caution, melting layer and CC data can now be used with great confidence in now-casting events I know I have a much better feeling for interpreting what the radar is telling me as a result of the Dual Pol products & residence training" ***RATING: 9***

Overall, the positive comments focused on the potential for using DP data 1) to explicitly determine the location of the melting layer, 2) to determine the precipitation type during winter events and delineate where rain/snow transition lines likely exist, particularly in areas where spotters or surface observations are sparse or inaccurate, and 3) to potentially bring a higher degree of confidence in short-term winter weather forecasting and now-casting.

3.1.2 Survey Results for Flash Flood Events

Forecasters also foresee the potential for DP to improve the effectiveness of the WSR-88D during flash flood events. The distributions of the WSR-88D effectiveness ratings for both the pre and post assessment surveys are shown in figure 9. Somewhat similar to what was seen in the ratings for winter weather there was a wide distribution in the pre-assessment ratings for flash flood events that narrowed and moved to the right in the post-assessment survey.

Pre-Assessment: Once again, an examination of the pre-assessment comments helps to explain the reason for the distribution seen in figure 9. Forecasters noted the ability to use WSR-88D base data to discern and track regions of high reflectivity, which have the potential for the heaviest rain. As for the WSR-88D algorithm to estimate rainfall, many limitations were mentioned. For example the challenge of determining whether rainfall estimates are too high due to hail contamination. They also mentioned the WSR-88D's dependence on a single reflectivity-to-rain rate (Z-R) relationship to estimate rain rates for a given time across the entire radar umbrella. The problem is for a given weather situation there can be a wide range of rain rates present in the data field at one time, e.g. rainfall can range from moderate to heavy with small to large drops within a given supercell complex. The following are some examples of comments:

"The 88D data does an excellent job of telling us where the strongest cores are located, and over what locations the highest reflectivity values dwell for the longest times. However, due to hail contamination, partial beam filling, beam blockage and reliance on Z-R relationships 88D precipitation estimates are often unreliable. The rainfall rate is most closely tied with the flash flood threat and the Z-R relationship is severely limited in this respect. Also, low echo centroid storms at far ranges are often under-sampled, with rainfall rates and flooding threat (assessment) severely limited. This is especially true at far ranges over mountainous terrain as in much of the western CONUS." ***RATING: 4***

"…..During widespread heavy rain events, the 88D is an absolutely essential and highly effective tool, as you are likely to have an adequate sample of rain gauge data to compare with radar estimates and make the appropriate calibrations. During more localized events, gauge data is likely to be more sparse, and it becomes necessary to make many informed but possibly inaccurate assumptions about the quality of the 88D's rainfall estimates (i.e., Is there hail contamination? Is beam blockage an issue? Is the currently employed Z/R relationship appropriate in this environment?, etc.)"
RATING: 7

DP Capabilities During Flash Floods: DP Flash Flood capabilities can address these forecaster concerns. DP base variable products are very important for the detection of heavy rain because they can be used to differentiate between tropical heavy rain with small drop sizes, continental heavy rain with moderate to large drop sizes, heavy rain mixed with hail, or large drops associated with small rain rates. All of this information is very useful for detecting the regions at risk for flash floods. Additionally, the Hydrological Classification Algorithm (HCA) uses DP variables to identify specific types of weather and non-weather radar echoes, such as birds and insects, rain, heavy rain, big drops, and rain mixed with hail. The DP Quantitative Precipitation Estimation (QPE) algorithm will compute rain rates based on these HCA classifications and their height with respect to the melting layer. In other words, one Z-R relationship is not used across the entire radar umbrella. Instead a specific rain rate relationship that uses other DP products is applied at each radar range bin depending on what is the most likely precipitation type. It is the combination of these advantages that has been shown will improve rainfall estimates.

However, work is needed to improve the performance of the DP QPE algorithm. For instance, one of the DP rain rate calculations is very sensitive to ZDR, hence the calibration of ZDR must be within 0.1 to 0.2 dB to get meaningful rainfall estimates. This is a challenging engineering target to reach and it may eventually require adjusting the QPE algorithm to compensate if the required calibration target cannot be achieved. Additionally, there will likely need to be algorithm "tweaking" when the DP upgrade is fielded in climatological regimes completely different than Central Oklahoma. It is because of the additional work required in these areas that both the legacy and the DP QPE algorithms and associated

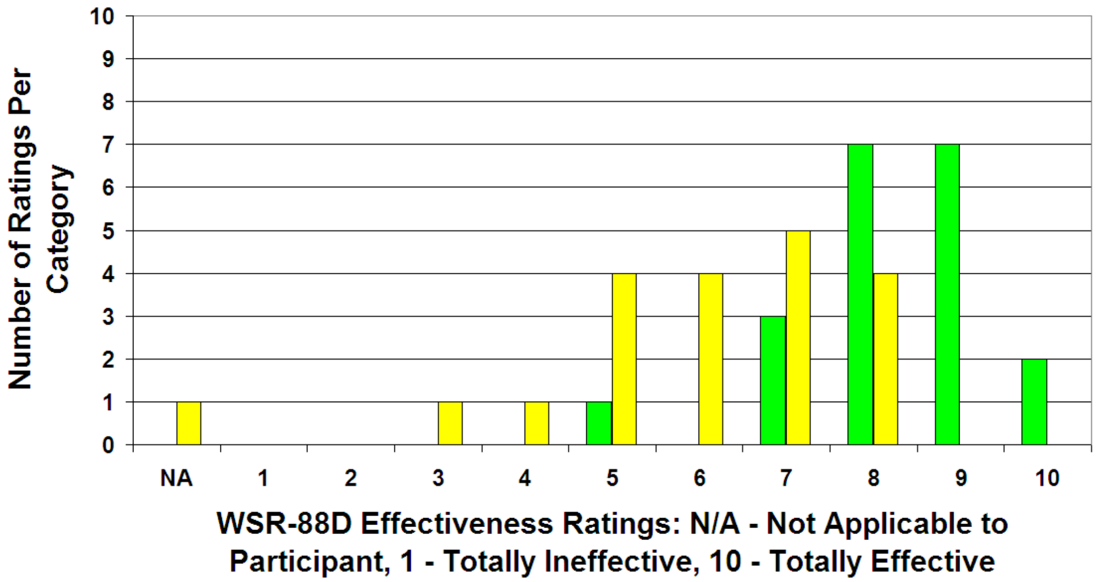

Figure 9: Distribution of the Pre (yellow) & Post (green) Assessment forecaster ratings for the effectiveness of the WSR-88D during flash flood events. Note the spread in ratings in the pre-assessment changing to a tighter cluster in the post assessment ratings.

products will be deployed to the field. That way, forecasters, still have use of the legacy precipitation products while work continues on the DP QPE products. These issues were discussed candidly with forecasters during the assessment so they would be aware of the issues.

Post Assessment: Referring back to figure 9, the results of the Post-Assessment survey show that forecasters foresee DP increasing the WSR-88D's effectiveness during Flash Flood forecasting and warning operations with nearly 80% of the comments positive. Nearly half of the positive comments specifically mentioned the utility of the DP base variable products to target the regions with the highest rain rates, even when reflectivity signatures are ambiguous. Three (out of 24) comments were negative and focused on some of the DP Quantitative Precipitation Estimation (QPE) limitations discussed during the assessment. Some examples of the negative comments were:

"…….. As was stated in the class, there is much work that still needs to be done on the QPE algorithms. I am a little concerned about the QPE data in tropical warm rain events. I would like to see significant improvements in these types of events." ***RATING: 7***

"…..However, it is worrisome that the DP QPE products continue to have trouble estimating rainfall in some situations, particularly in tropical environments. It appears that until this issue is resolved, forecasters will not be able to completely "load-shed" the legacy precipitation products. Although it is impossible to develop a perfect radar-derived precipitation estimation product, if the DP QPE products cannot be show to be a

major improvement over the legacy products, I'm afraid operational forecasters may view the DP products as "one more damn thing I have to look at during hydro events." ***RATING: 8***

Note that the negative comments are associated with the QPE algorithm; yet forecasters still gave overall high ratings for the DP data. Some positive comment examples are:

"After looking at the dual-pol data I think the biggest improvement over the current configuration will be in identifying the flash flood threat. Being able to identify whether an area is pure heavy rain or a mix of rain and ice will be beneficial. The KDP(Specific Differential Phase), Correlation Coefficient (CC), and Differential Reflectivity (ZDR) products will all be helpful." ***RATING: 7***

"Better able to identify areas of heavy precipitation over the standard radar, especially KDP." **RATING: 9**

"…….The use of KDP to help ascertain precipitation loading/rain rate and ZDR for drop size was a great help in building my conceptual model of the ongoing processes in the cloud. Elevated KDP would definitely point me to potential areas for flash flooding, especially embedded within a broad area of heavy rain. I'm sure it will also help our other forecasters." ***RATING: 10***

"There is great potential to assist us in monitoring and pinpointing heavy rain threats using dual pol radar, with the availability of KDP. Once the precipitation algorithms are improved, I suspect this data will become exceptionally robust." ***RATING: 8***

Overall, forecasters viewed the DP base variable products as very relevant to forecasting operations and the potential of better precipitation estimates via DP QPE to be a great help for their operations.

3.1.3 Survey Results for Severe Convection (severe winds & hail)

Forecaster ratings also indicated DP could increase the effectiveness of the WSR-88D during Severe Convection operations, although less than seen with the rating changes for Winter Weather and Flash Floods. Here we use severe convection to mean the threat of severe winds and hail. The distributions of the WSR-88D effectiveness ratings for both the pre- and post-assessment surveys are shown in figure 10. In this case, the pre-assessment ratings were clustered around a rating of seven; the post-assessment ratings were a little broader but were clustered around eight. This indicates that forecasters already considered the legacy WSR-88D to be fairly effective for interrogating Severe Convection, hence the expectation of modest improvement with the DP upgrade.

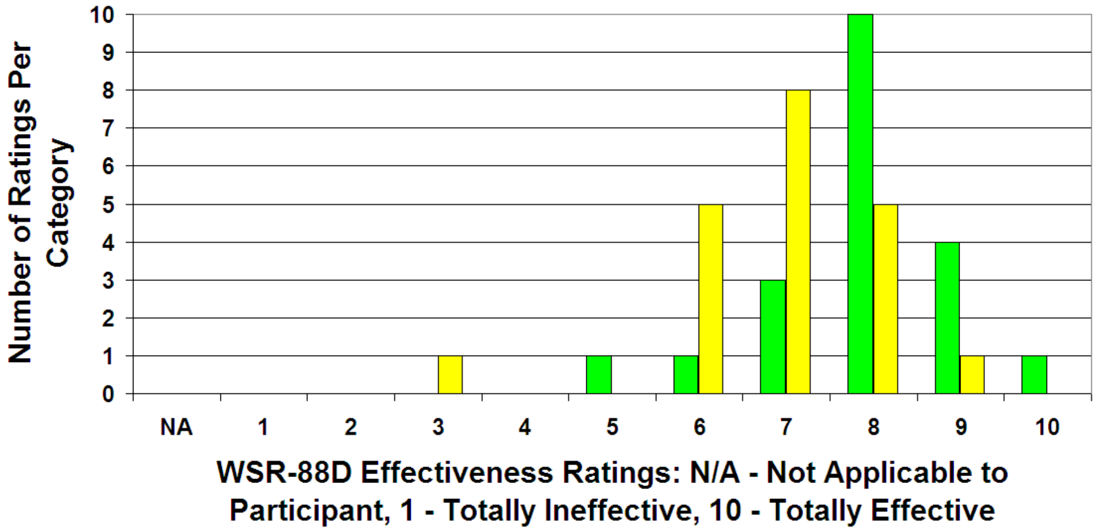

Figure 10: Distribution of the Pre (yellow) & Post (green) Assessment forecaster ratings for the effectiveness of the WSR-88D during severe convection events. Note that in this case, the distribution cluster in the pre-assessment ratings moved right in the post assessment survey.

Pre-Assessment: The pre-assessment comments noted, in general, that the current WSR-88D is not very effective at capturing the distant and micro-scale convective wind events, and that it is also difficult to discern between non-severe and severe hail. Some specific comments below:

"The WSR-88D in its current configuration is actually quite effective in evaluating the potential for large hail, as well as for organized, dynamically driven convective wind events (i.e., bow echoes). However, where the WSR-88D falls short is in assessing the potential for smaller scale wind events (i.e., microbursts). These appear to occur on time and spatial scales too small for the 88D, in its current configuration, to effectively provide adequate information to support successful warning decisions. This is a problem for those of us along the southeast Atlantic coast, since studies show this is our most common form of severe weather." ***RATING: 6***

"The problem with the current WSR-88D is its inability to discriminate between storms with low-end severe hail and those with very heavy rain and large amounts of small hail. We believe the great majority of high dBz storms in our area fall into the latter category." **RATING: 3**

DP Capabilities During Severe Convection: Initially, the greatest benefits to incorporating DP products into the severe convective analysis is for the detection of hail of any size, and for the detection of giant hail, defined as larger than golf-balls or 2 inch diameter or more. Using DP base products, forecasters are able to detect giant hail even when reflectivity signatures may be ambiguous, increasing confidence in the potential for a significant hail event. Additionally, DP base products allow for the presence of any sized hail at the height of the radar beam, and whether that hail is in the process of melting. Unfortunately, base data analysis for DP products at this point does not add much value in determining whether hail is not severe or has just exceeded severe limits, e.g. whether it is greater than or equal to ½ , ¾ or equal to 1 inch in diameter depending on the agency. There is hope that an algorithm may be developed that will help with this issue. In terms of severe winds, it does not appear that DP data will add much value over current WSR-88D products at this time. There are many good research ideas out there in terms of increasing lead time for small-scale convective wind events, but they have a long way to go before they might be accepted in an operational setting.

Post Assessment: The Post-Assessment survey comments reveal why forecasters only foresee a modest increase in effectiveness in the WSR-88D for interrogating severe convection. In particular, forecasters noted the need to discern between non-severe and severe hail size: 1 inch or greater for NWS, greater than or equal to ½ inch for the Army and greater than or equal to ¾ inch for the Air Force. As discussed previously, currently, there is no algorithm using DP data that is sophisticated enough to provide this information. Yet this information is very important when considering whether to issue warnings for marginally severe storms. Additionally, they did not see DP data adding value to the prediction or detection of damaging winds. Nonetheless, forecasters noted that DP data 1) increased their awareness of where hail was located within storms, 2) helped them distinguish whether or not hail is of extreme size (> 2 inches) and 3) helped them target storms with strengthening updrafts, hence needing closer monitoring. Of the 23 comments, 65% were positive and 35% were neutral. The following are some neutral comments:

"……..I would rate this higher if we had the capability to distinguish severe hail (one inch) vs "giant" (two inch+) hail. As noted in my pre-assessment comments, most of our storms are pulse with 1-2 supercells per year so it is this "marginal" realm that would provide the biggest operation improvement for us." ***RATING: 7***

*"Dual-Pol data can be used to help identify areas of very large hail and the location of updrafts, which I can see adding some value when interrogating severe convection. However, based on what we've learned so far, I do not think there will be *significant* value added for interrogating a severe wind/hail threat."* ***RATING: 8***

Some examples of positive comments are the following:

"I think that dual pol variables will be used in our office quite a lot in determining the location of hail (using ZDR/CC) as well as the location of the heaviest rain shafts (KDP). I think the variables give good insight in being able to assess not only the threat but also helps to fill in the gaps in the conceptual picture of individual storm structure."
RATING: 9

"Inclusion of dual pol variables into the radar product suite most definitely improves a forecaster's ability to assess the hail and flash flood potential. The common-sense approach to begin storm interrogation by examining what you know, then incorporating the dual pol information, is excellent, and will be an 'easy sell' to my forecast staff. It's

critically important that all forecasters physically understand what each dual pol variable is/how it's computed…that way, they'll be better able to understand how inclusion of those data will aid in their warning-decision making." ***RATING: 8***

3.1.4 Survey Results for Tornado Events

Forecasters did not believe DP would change the WSR-88D's effectiveness during tornado warning operations in terms of increasing tornado warning lead time. Figure 11 shows the distribution for the pre & post assessment survey ratings. In both cases there is a broad distribution with the most common score in both surveys remaining "8." An analysis of the comments provides some insight.

Pre-Assessment: Forecasters have noted that the radar is effective for rotating supercells; however, it is not as effective for small scale circulations associated with non-supercell tornadoes. Some examples of the pre-assessment survey comments are the following:

"The 88D is extremely useful in assessing the potential for one type of tornado: the classic supercellular type. Since these account for the vast majority of significant tornadoes, and almost all violent tornadoes, this is a good thing. However, for those of us on the east coast, supercell tornadoes account for only about 10% or so of our tornado events. Most of the events in the east occur in weakly unstable, strongly sheared environments, and are therefore the result of mini-supercells or form under non-mesocyclonic processes (i.e., shallow quasi-liner systems). While most of us have learned to re-calibrate our radar interrogation of mini-supercells, non-supercell tornadoes developing in strongly sheared/weakly unstable environments continue to be the Achilles heel of severe weather forecasters in the East. Time and spatial scales are simply too small for the 88D to be of much use in these situations." ***RATING: 5***

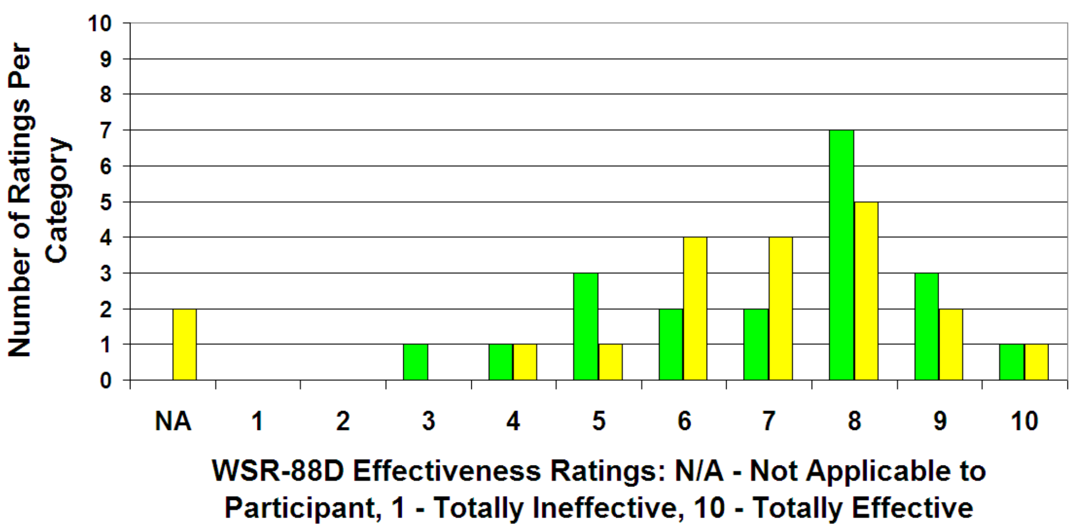

Figure 11: Distribution of the Pre (yellow) & Post (green) Assessment forecaster ratings for the effectiveness of the WSR-88D during tornado events. Aside from the higher maximum in effectiveness, the post-assessment survey distribution remained broad.

"The 88D does well with supercell tornadoes especially if the warning meteorologist is aware of the near storm environment. It does not do well with landspout situations due to the low level processes involved and beam over-shooting taking place." ***RATING: 6***

"All-tilts of Z/SRM is the most useful tool for determining tornadic potential, but even that approach doesn't provide much help here. Storms that spawn tornadoes are not typically supercells, and even when supercell storms occur, they are typically quite small compared to storms out east, due to the lower CAPE and weaker vertical shear environment we experience over the lower desert. Once in a while, northern Arizona finds itself in a favorable environment to support long-lasting supercell storms (mdt/strong shear, mainly unidirectional, coupled with modest CAPE)." ***RATING: 7***

DP Capabilities for Tornado Operations: The use of storm relative velocity in conjunction with DP base variable data, in particular CC and ZDR, can help identify regions of airborne tornadic debris. Tornadic debris identified from using the radar products confirms the presence and location of a damaging tornado. A caveat is this signature will usually only be detected close to the radar, generally within 60 nm. Additionally, the tornado has to loft debris high enough and at the same time the radar is scanning the area for it to be sampled by the radar. This is actually more common than you might think because relatively small, easily lofted debris can occur even in relatively weak tornadoes. Debris such as leaves, twigs, grass, insulation, etc. are easily lofted thousands of feet in the air and produce a unique signature in the DP products. What remains to be seen is how the debris ball signature may vary over other regions of the U.S or how or if it can be detected for non-supercell tornadoes. Nonetheless, tornadic debris detection is very useful, particularly if one is located in a region where spotter reports are sparse and/or during night-time tornado events. Because identifying debris implies the tornado is in progress, e.g. on the ground, there is no initial lead time with the signature. At this time, research has not been able to come up with ways to use operational DP products to directly increase tornado warning lead time.

Post-Assessment: From the post-assessment survey comments, forecasters noted that DP products would not add any value over what is currently available in the legacy WSR-88D base products for issuing a tornado warning. However, forecasters did note the potential for DP data confirming the presence of a damaging tornado for storms close to the radar, a great asset at night or in spotter-sparse regions. Forecasters noted this would 1) enhance their situational awareness, 2) provide a way to communicate the tornado threat more effectively to the community via follow-up severe weather statements and direct communication with their partners, and 3) help in tornado track analysis for damage surveys. Of the 29 post-assessment comments provided, 59% were positive, 38% were neutral and one was negative. Some examples of the positive comments are the following:

*"Tornado debris signatures with DP data will certainly help in the more explicit detection of locations where debris is being lofted and damage is occurring - this will enhance forecaster situational awareness and confidence - however this still has no predictive value……." **RATING: 8***

"…….using the CC and ZDR to determine the potential for debris will likely aid in increased threat wording in the (communication of) severe weather statements as well as aid in where to focus a post storm survey team." ***RATING: 5***

"**Using Dual-Pol data to identify debris can definitely add value to tornado warnings by identifying that a damaging tornado has been confirmed, and, when Dual-Pol rolls out, I see this as a signature that we will all be closely looking for when dealing with potentially tornadic convection."* ***RATINGS: 6

The one negative comment was a concern about the potential loss of velocity data due to the inherent sensitivity loss associated with the DP hardware upgrade and is the following:

"A potentially significant downside to the change to Dual Pol is due to the 4 dB reflectivity sensitivity loss. The example provided of the extremely unusual EF3 tornado in Colorado showed that even in that case with considerable reflectivity in the hook echo, the area of good velocity data in the lower reflectivity regions surrounding the tornado were reduced by about 50%. Many EF0-EF3 tornadoes occur with substantially less reflectivity than the example provided, with more Low Precipitation-ish supercells, or with classic supercells at the onset of the tornado. These potential issues should be looked at carefully." ***RATING: 3***

This post-assessment comment and its associated rating is part of the reason why figure 11 shows a slight decrease in the perceived effectiveness of DP data in regards to Tornado Warning Operations. We will address this and the other comment concerning sensitivity and the potential to impact winter weather events in section 4.

3.2 Forecaster Summary Results

At the end of the Operational Assessment forecasters were asked to answer the key questions based upon their experience during the operational assessment. These questions were 1) what they believed were the top benefits DP data provided to their operations, 2) the top challenges they faced in implementing DP data into their operations and, 3) in their opinion, what should be the top DP research and development areas. Table 5 below lists the top results from question 1.

<u>DP Top Benefits</u>: The benefits most often noted by forecasters (33% of the total) were those related to providing better capabilities during heavy rain events, that is, the ability to target the location of heavy rain and the potential for better rainfall estimates. Specifically, DP data allowed forecasters to identify regions where the heaviest rainfall could be expected, hence the highest risk for flash floods. Forecasters also noted that with the incorporation HCA data into the DP QPE algorithm, the reliance on a single Z-R relationship will be greatly lessened. The HCA classifies the radar echo using all the DP products as input, and assigns a representative rain rate to the DP QPE algorithm.

Table 5: The top DP benefit/improvements noted by forecasters as based upon their experience during the operational assessment.

KEY DUAL POLARIZATION BENEFITS	NUMBER OF TIMES CITED/PERCENT OF TOTAL (57) COMMENTS
Rainfall Related Improvements: Identifying areas of heavy rain/potential for improved rainfall estimates	**19/33%**
Improved Severe Convection Interrogation: Improvement in identifying key features in severe convection, e.g. detection of tornadic debris, hail detection, updraft strength	**18/32%**
Winter Weather Benefits: Improved ability to discern precipitation type during winter weather	**14/25%**
Other: Improvements in: distinguishing between Non-Meteorological and Meteorological echoes, identifying melting layer, understanding the forecaster conceptual model, potential for fire weather	**6/10%**

Another, almost equally important, benefit was the improved ability to identify key severe convection features, such as tornadic debris, the location of hail, and strong, persistent updrafts. Forecaster comments noting these improved severe convection interrogation benefits comprised 32% of the total number. The third most mentioned benefit, improved capability during winter weather was mentioned 25% of the time. The following are some examples of forecaster comments, extracted from their summaries, concerning DP benefits:

"The (DP) QPE algorithm seems to offer a great deal of improvement over the (legacy) Doppler algorithms because of the ability to use different (rainfall rates) for different hydrometeor classifications.………The Base DP products by themselves will improve forecaster situational awareness during heavy rainfall events due to improved understanding of drop sizes, precipitations rates and any hail or ice contamination."

"Determining the melting layer using the CC and to a lesser extent KDP will help to identify snow levels within winter storms. This has a huge impact on offices with complex terrain………it will not only aid situational awareness of snow levels but also help determine precipitation rates over the terrain…."

"The Dual Pol variables appear to do an admiral job of displaying when hail is possible, via utility of the CC and ZDR. This should be one of the most used utilities when

determining hail threat vs. heavy rain threat, or simply increasing confidence in which threat is most likely and where….”

Top Challenges: Forecasters also noted what they believed would be the top challenges they faced when implementing DP data into operations and these are listed in Table 6.

Table 6: A list of the challenges faced when implementing DP data into operations as listed by forecasters. List based upon feedback during the operational assessment.

TOP DUAL POLARIZATION CHALLENGES	NUMBER OF TIMES CITED/PERCENT OF TOTAL (49) COMMENTS
Integration/Transition/Develop Expertise: Integrating the data into the forecast office, transitioning its use into operations and developing expertise	**20/41%**
Training: Critical to ensure DP training is available prior to the deployment of DP to the field.	**15/31%**
Workload: Concern over the increased number of products may initially cause some information overload	**11/22%**
Other: Getting Differential Reflectivity properly calibrated, challenges with introducing DP data to media, developing climatology with DP data	**3/6%**

All comments regarding the integration and transition of DP data into operations and the development of forecaster expertise were put into one category: developing expertise. The reason is each of these areas is important in the process of developing forecaster expertise. Comments that fit into this category comprised 41% of the comments on top challenges. For the forecaster, it was important to develop a "comfort level" with the new data and to have confidence in their capabilities. Some key comments concerning this challenge were the following:

"By far, the largest challenge will be developing a comfort level when using these new variables. Each forecaster will need to have confidence that these variables actually provide useful information."

"Integration (of Dual Pol data) into the severe thunderstorm interrogation process, I feel, will be one of the biggest challenges."

Forecasters believed training was the next most important challenge with 31% of the comments related to this topic. The following comments confirm this:

"Major technological changes are typically met with some resistance at the field level and if the benefits of the changes are not made extremely clear, the DP products will not

be used……..While this is partly a WDTB issue, I think its mainly going to fall on local training personnel at the WFO level to bang the DP drum."

"I think training will be the most crucial aspect of implementing the Dual Pol products into office operations….."

"…..training must particularly address how Dual Pol products will make their job easier…not simply be another suite of products for which there are ambiguous uses."

"……basic training of theses new (DP) base variables and derived fields will require a considerable, lengthy and sustained training effort at the national, regional, local and individual levels."

WDTB has long understood the challenge of training forecasters on how to integrate DP data into their forecast and warning processes. However, what was enlightening was just how crucial the development of expertise will be after an office starts receiving DP products. In light of this, WDTB plans on developing "continuous learning" tools designed to develop forecaster expertise. These tools include bi-weekly webinars that show interesting DP data from beta test radars and eventually data from follow-on DP upgraded radars. WDTB will have online and on via AWIPS workstations reference tools, e.g. "cheat-sheets with fundamental DP product information, that are easily accessible to the forecaster and provide quick refreshers on DP products and product signatures. All these continuous learning tools go above and beyond the traditional recorded, online training modules. The online training modules for NWS meteorologists and for non-NWS meteorologists are available now, accessible from the following web address:

http://www.wdtb.noaa.gov/courses/dualpol/

The WDTB site contains training for the key DP radar products, e.g. Correlation Coefficient, Differential Reflectivity, Specific Differential Phase, Melting Layer, Hydrometeor Classification and DP QPE products. WDTB also has training modules that focus on the key forecasting applications related to these DP products.

The third most mentioned challenge to implementing DP products into operations was the workload increase perceived with the addition of the new products. Their concern is that examining so many new products may impact their situational awareness during forecasting and warning operations. The following are some key comments made concerning this issue:

"Highly proficient warning meteorologists will not see much workload issues incorporating the new data into their analyzing schemes. There are many meteorologists…..that become overwhelmed during severe weather and flash flooding situations. Its will be a challenge for those individuals to incorporate the Dual Pol products in higher (incidence) severe weather regions of the CONUS………"

"Forecasters are going to have to be smart and selective in how they work Dual Pol data into their forecasting and warning processes. We are going to have to understand our own "human bandwidth" and how best to "load shed" information that doesn't contribute directly to the task at hand."

"……the forecaster is inundated with a gargantuan amount of data and information (not just radar data) and we continue to ignore the implications of information saturation and overload. The answer I've heard in regard to DP is that we can continue to use legacy data/products and we don't have to use the DP data. This seems like an implicit recognition of this issue without actually addressing it head on."

The key to solving this problem will be training and developing forecaster expertise. As forecasters develop expertise in integrating DP data into their forecast and warning processes, they will be more comfortable examining the products hence, gaining the maximum benefit for a particular weather event without sacrificing situational awareness or warning lead time.

Top Research & Development Areas: Finally, forecasters noted a variety of potential DP research and development areas. However we list the top two noted by forecasters: 1) work to refine and improve the DP QPE estimates and 2) to develop a method for DP to explicitly discern between non-severe and severe hail size, a parameter dependent upon the customer, hail size. Continued work on the DP QPE algorithms was expected as DP is fielded to climatic regimes substantially different from central Oklahoma. This is the main reason why the legacy precipitation algorithms will remain as the DP QPE products are fielded. Work on hail size was most important to the forecasters in portions of the Western and Southeastern U.S. as significant hail events are less frequent than those experienced in the Plains and the hail size is more likely to be in the ½ to 1" size range.

4. Sensitivity Loss for Key Meteorological Features

Prior to the Operational Assessment, a sensitivity study was conducted to determine the impact to operations of a 3dB sensitivity loss on the WSR-88D's operational products and this was documented in Scharfenberg, et. al., 2005. Using KTLX (Twin Lakes, OK) Level II radar data, the sensitivity of the data was reduced by 3dB in a manner very similar to what was discussed in section 2.2.3. In all, over 16 hours of radar data spanning six different weather cases were examined in this particular study. The cases chosen included a variety of weather regimes: a winter storm case, two cases of light precipitation (not wide-spread), one case of clear air signatures prior to storm initiation, one case of tornadic supercells and a final case with widespread hail-storms. The results indicated that, in general, major meteorological features such as fine line signatures, hook echoes, precipitation bands, etc. showed little or no change after the radar data's sensitivity was reduced by 3 dB. The radar echoes lost were those with weak reflectivity along the fringes of precipitation returns, those related to anomalous propagation and weak reflectivity clear air scatterers.

In addition, a test, using real-time data, was conducted using field forecasters from the Norman Weather Forecast Office (WFO) and NSSL staff members. In this test, forecasters were able to view KTLX data alongside data that was reduced by 3 dB (denoted as KROC data) via AWIPS during routine forecasting operations. Both WFO and NSSL forecasters did not observe any significant differences when examining the two data sets in real-time. Important weather features such as clear-air boundaries and gust fronts were sometimes diminished but human detection was not generally impaired. Differences in velocity de-aliasing errors between the legacy and reduced sensitivity also didn't appear to affect operations. Additionally, changes to products and algorithms such as Vertically Integrated Liquid, Mesocyclone, Hail Detection and Echo Tops appeared trivial. The most noticeable changes were seen in VWP output as the highest altitude data points were lost in the KROC data, but occasionally those data points were already considered suspect. Participating forecasters did not report these VWP differences as adversely impacting their operations.

During the Winter 2009/2010, a careful ROC Engineering analysis determined the total sensitivity loss expected for any particular radar in the WSR-88D fleet after the DP upgrade is expected to be 3.5 to 4 dB (ROC Technical Report III, 2010). This value is slightly higher than the 3 dB sensitivity loss tested in the previously discussed study. A Subject Matter Expert (SME) Panel, held in December 2009, looked into the potential operational impact of a 4 dB or higher sensitivity loss. The panel, composed of WDTB, ROC, NSSL, Norman WFO and OU research staff, looked at data that was crudely reduced to simulate a 4 dB sensitivity loss. The data included examples of weather phenomenon from a wide range of radars across the U.S. Their conclusion, based upon the data reviewed, was that a 4 dB sensitivity loss should not significantly impact forecasting operations.

An additional SME Panel held in March 2010 looked further at potential impacts of a 4 dB sensitivity loss. The panel composed of WDTB, ROC, NSSL, Office of Hydrologic Development and two NWS Regional Scientific Services Division Chiefs also looked at radar data with legacy and reduced sensitivity for a wide range of meteorological phenomenon from a number of radars across the U.S. However, this time the technique used to reduce the sensitivity was that described in section 2.3.3 and used in the Scharfenberg, et. al. (2005) study. Once again, based upon the review of the data, the conclusion reached by panel members was that a 4 dB sensitivity loss would not have a significant impact on forecasting operations.

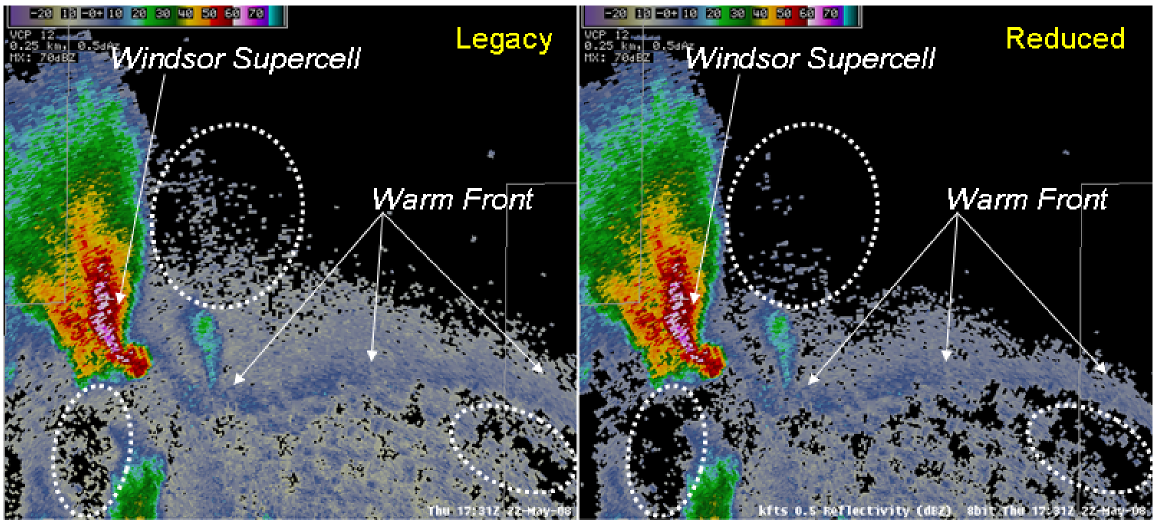

Figure 12 Half degree base reflectivity at legacy, left, and 4 dB reduced sensitivity, right, for the Windsor, CO supercell, at 1731Z on 22 May 2008. There are no discernible changes to the supercell structure and the warm front remains clearly visible albeit with less power return present in the white-dashed ovals in the reduced sensitivity example.

Nonetheless, we wanted to ensure that the topic of a 3.5 to 4 dB sensitivity loss was discussed during the Operational Assessment. We did this by showing the SME panel examples of meteorological radar signatures at legacy (i.e. full strength) and a 4 dB reduction in sensitivity for the same radar and a wide range of events across the U.S. (ROC Technical Report, 2010). From this sensitivity demonstration, we received three comments concerned with the loss of sensitivity, the strongest of which is mentioned in section 3.1.4. Figures 12 - 14 show the effects of a 4 dB sensitivity loss for an EF3 tornado near Windsor, Colorado. The forecaster comment about the adverse effects of a 4 dB sensitivity loss specifically mentioned this event and was the focus of his concern. Figure 12 shows the key meteorological features visible in reflectivity: the tornadic supercell and the warm front. It is clear that there is some data loss, particularly along the fringes of the weather echoes in areas of low signal-noise-ratio, consistent with the findings of all previous studies and SME panels. Nonetheless, the important meteorological features relative to the storm remain visible in reflectivity data. Figure 13 shows 0.5 degree reflectivity and storm relative velocity images for the very next volume scan. There is clearly a loss of some velocity data but comparison with the reflectivity image shows the lost data lost has weak signal, generally less than 0 dBZ (data colored with shades of gray). The mesocyclone and tornadic vortex signature are still clearly visible in the reduced sensitivity

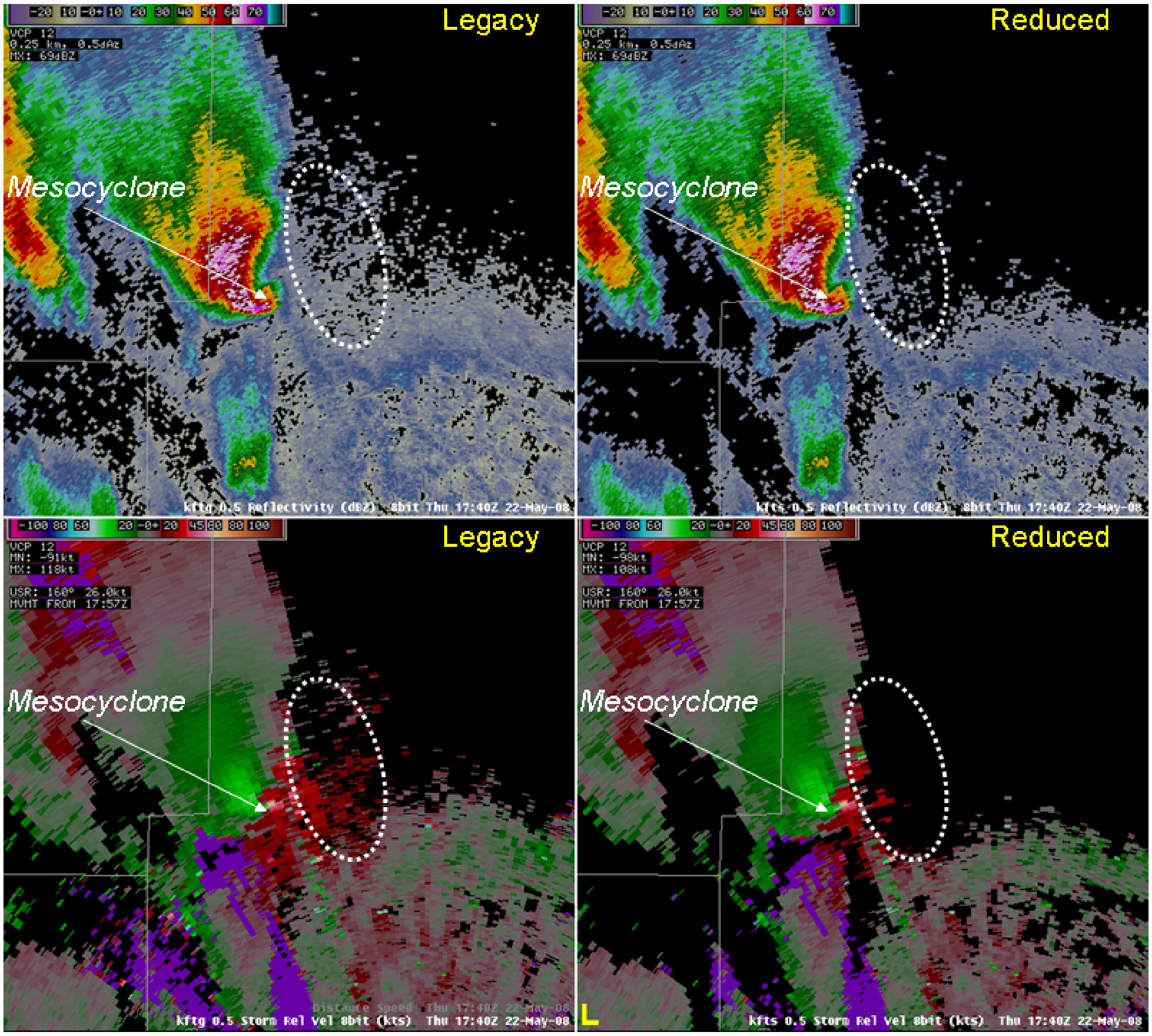

Figure 13: Half degree base reflectivity and storm-relative velocity images at legacy (Top Left, Bottom Left) and 4 dB reduced sensitivity (Top Right, Bottom Right) for the Windsor, CO supercell, 1740Z on 22 May 2008. Note the loss of low signal-to-noise ratio data in reflectivity and velocity data (white dashed ovals); nonetheless, the mesocyclone is clearly visible.

image. The storm at this time was located 38 nm north-northwest of the Denver radar (KFTG).

Figure 14 shows storm relative velocity, at legacy and 4 dB reduced sensitivity, for two consecutive volume scans. Once again, there is some velocity data lost but the mesocyclone and the tornadic vortex signature are still clearly visible in each volume scan. This remained the case for each volume scan reviewed for this weather event (not shown).

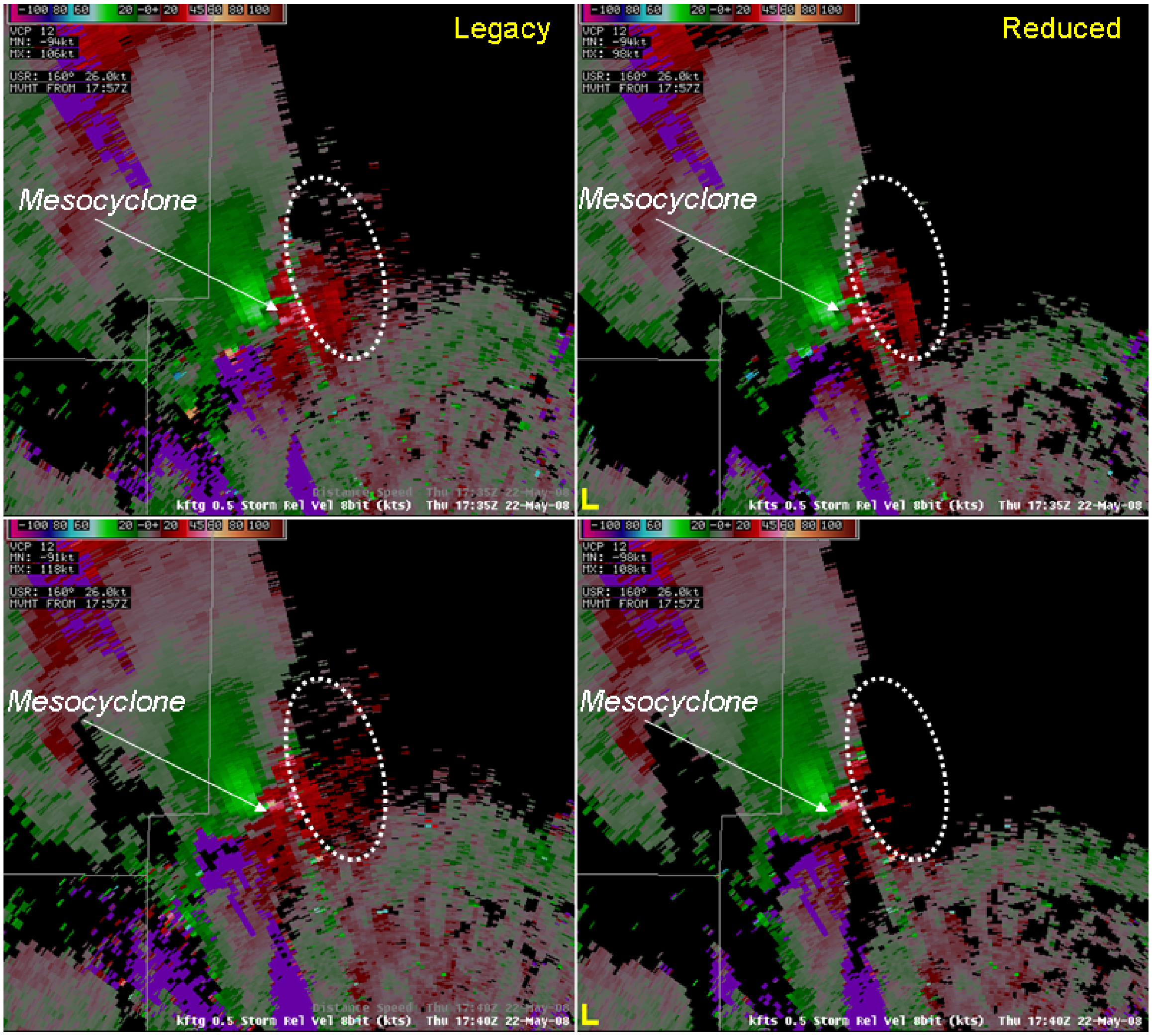

Figure 14: Half degree storm relative velocity images of the mesocyclone at legacy (Top Left, Bottom Left) and 4 dB reduced sensitivity (Top Right, Bottom Right) for two consecutive volume scans, 1735Z (Top) and 1740Z (Bottom), for the Windsor, CO supercell. In both images, velocity data with low signal-to-noise ratio is lost (white dashed ovals) but the mesocyclone is clearly visible in both images.

We also examined, at legacy and 4 dB reduced sensitivity, several tornado cases that occurred in the Southeast U.S. and these are shown in figures 15 and 16. Figure 15 shows 0.5 degree base reflectivity and base velocity data, at legacy and 4 dB reduced sensitivity, for the EF2 rated Jasper, Mississippi tornado on 24 April 2010. Once again, it is clear that the loss of data due to the reduced sensitivity does not affect the ability to discern the supercell's structure and attendant mesocyclone. At the time, the storm was located 46 nm east-southeast of the Jackson, Mississippi radar. Figure 16 shows a supercell thunderstorm near Monticello, Georgia. As in the previous cases, there is velocity data loss due to the reduced sensitivity but nothing that would preclude a forecaster from tracking the mesocyclone. Data loss in both cases was in regions of weak signal-to-noise ratio with reflectivities generally lower than 5 dBZ. Training from

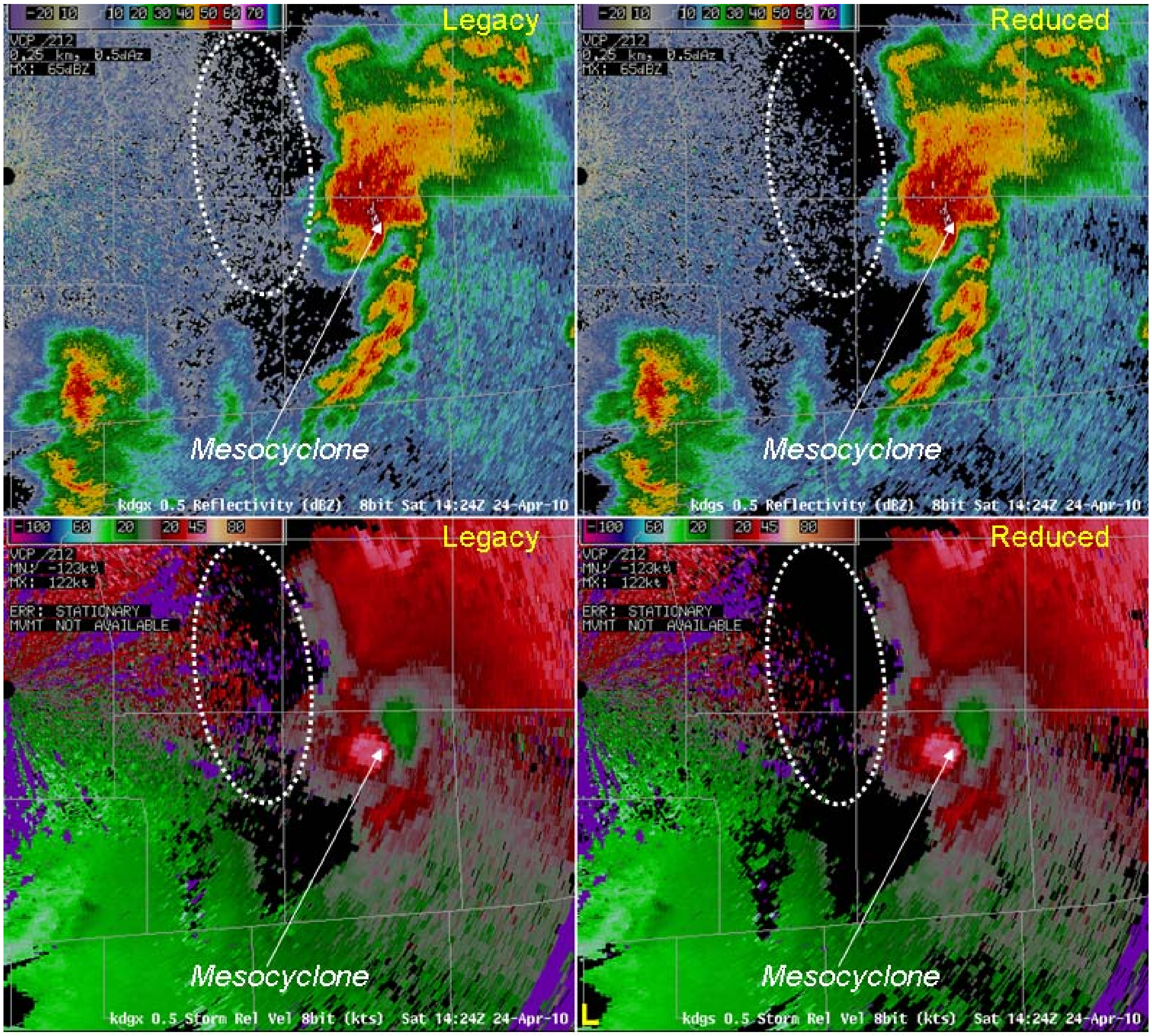

Figure 15: Half degree base reflectivity and base velocity images at legacy (Top Left, Bottom Left) and 4 dB reduced sensitivity (Top Right, Bottom Right) for the Jasper, MS supercell, 1424Z on 24 April 2010. Although there is some loss (white dashed ovals) of low signal-to-noise ratio data due to the reduced sensitivity, the main features of the supercell and the attendant mesocyclone are plainly visible.

WDTB will address the impacts to a 4 dB sensitivity loss, drawing from the events shown at the Operational Assessment.

During the assessment, we also showed forecasters the effect a 4 dB sensitivity loss could have on a number of meteorological features. Figures 17 – 20 show several examples. Figure 17 shows, at both legacy and 4 dB reduced sensitivity, a dry line passing through Dodge City, Kansas. In this particular case, the dry line can be seen at a greater distance at legacy sensitivity. At 1609Z, the dry line is visible to a distance of about 70 nm south of the radar at legacy sensitivity; in reduced sensitivity, the dry line is clearly visible at 45nm and there are some weak pixels associated with it to near 60 nm. The data lost are pixels with lower signal-to-noise ratio data causing the dry line signature to be harder to

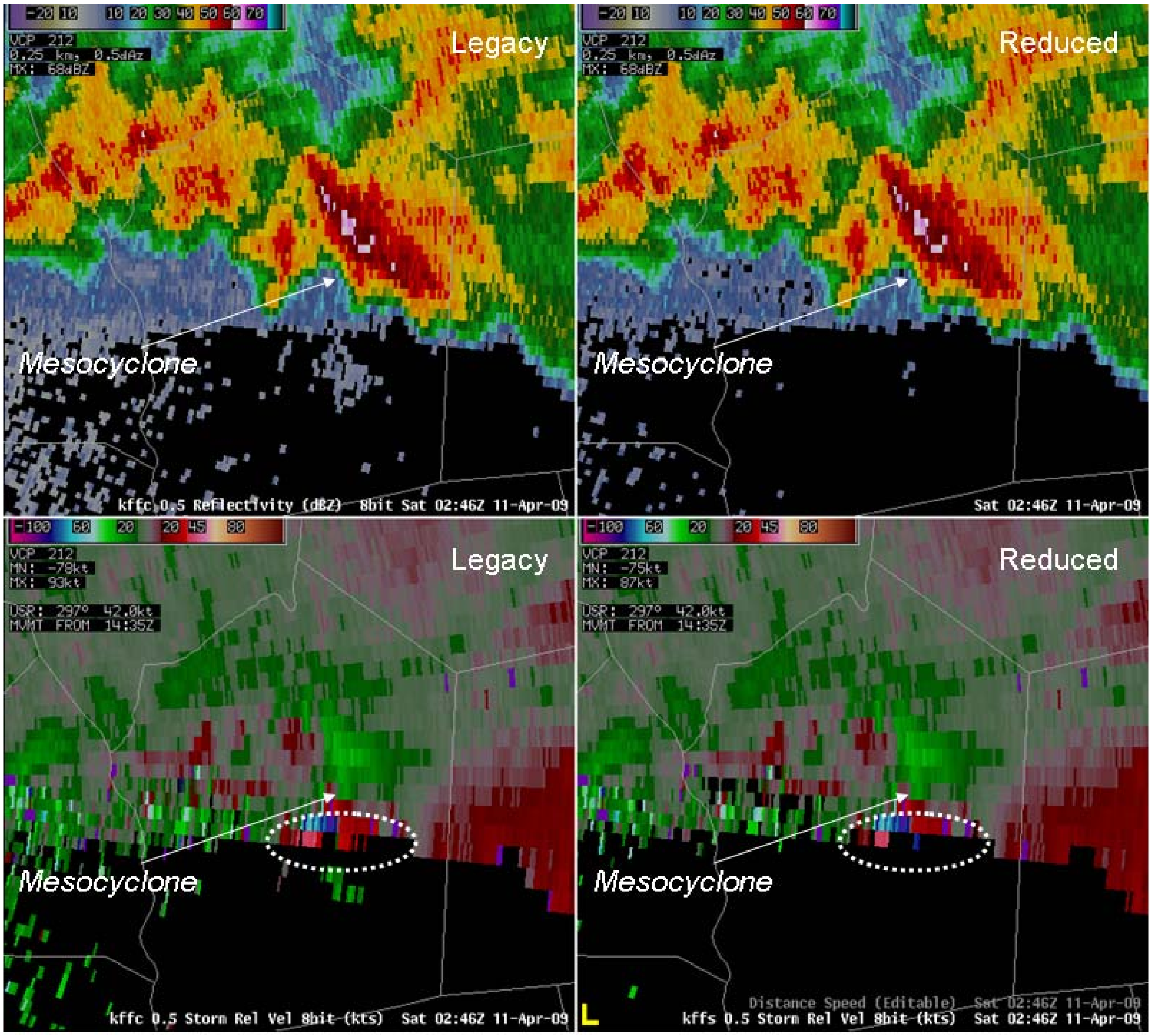

Figure 16: Half degree base reflectivity and storm relative velocity images at legacy (Top Left, Bottom Left) and 4 dB reduced sensitivity (Top Right, Bottom Right) for a supercell in Jasper County, GA on 11 April 2009. In this example, there is a slight loss of velocity data; however, the mesocyclone feature is remains clearly visible at a distance of 47 nm from the radar.

discern at greater distances with reduced sensitivity. By looping the reflectivity images, forecasters were able to identify the location of the dry line at far range much better than a single static image of the reduced sensitivity data. Thus, forecasters felt that even though at far ranges this dryline did not show up as well as the full sensitivity data, they were able to identify it nearly as far using looping. Most importantly, convective initiation is clearly visible even in the reduced sensitivity image at 1621Z.

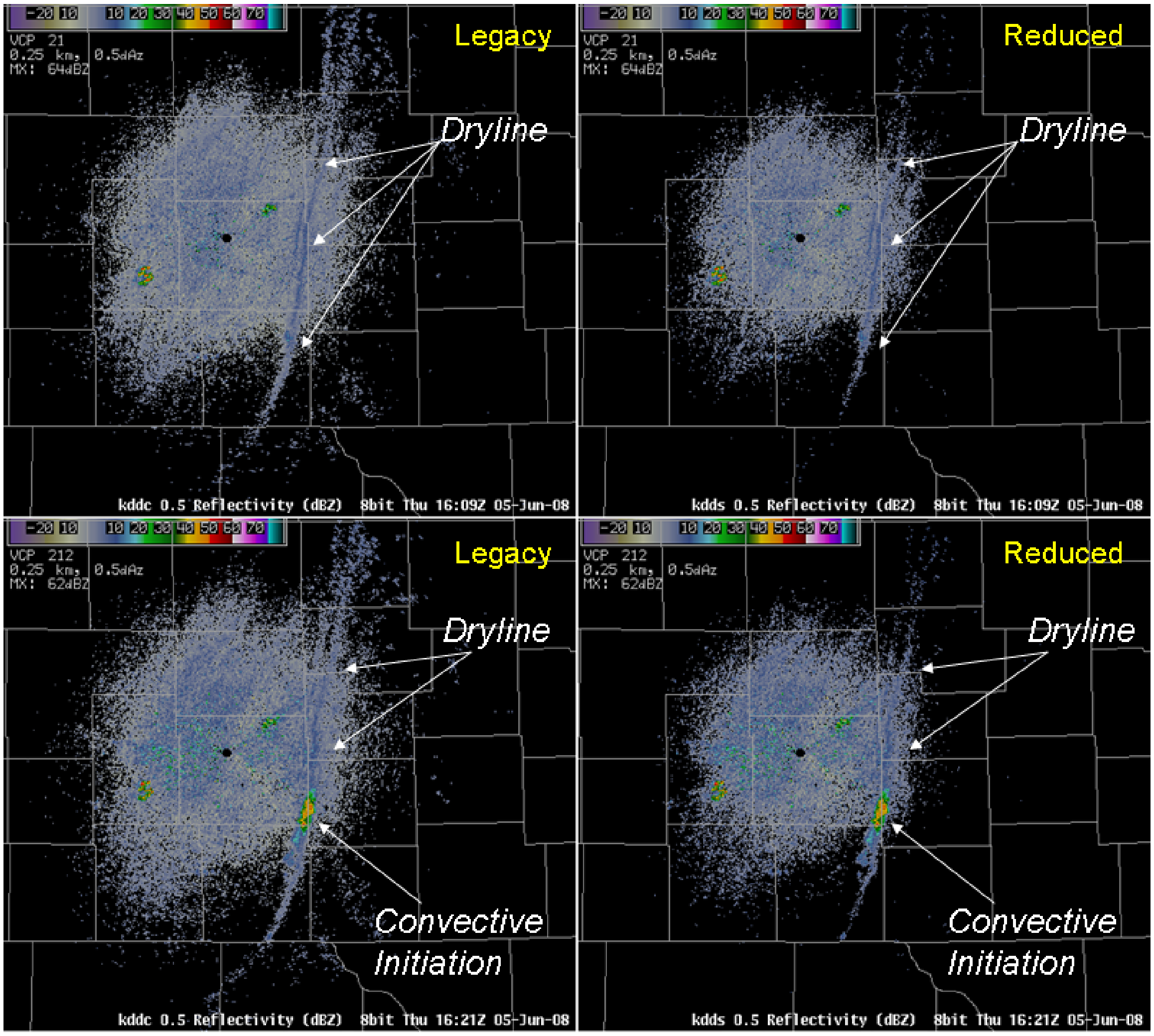

Figure 17: Half degree base reflectivity at legacy (Left Top, Left Middle, Left Bottom) and 4 dB reduced sensitivity (Right Top, Right Middle, Right Bottom) at 1609 and 1621Z for a dryline passing through Dodge City, KS.

Figure 18 shows an example of summertime thunderstorms and their associated outflow boundaries along the Florida Panhandle. Outflow boundaries are still clearly visible at legacy and reduced sensitivity imagery at 1903 and 1909Z. In fact, outflow boundaries could be detected at distances greater than 50 nm at both legacy and reduced sensitivity. Earlier in the data, between 1559 and 1708Z (not shown), a weak sea breeze could be detected at both legacy and reduced sensitivity. Via animation, the sea breeze could be seen developing along the coast and eventually initiating a few thunderstorms. Overall, these clear air features at reduced sensitivity are slightly less apparent at greater distances.

As mentioned previously, there were two comments, one in a post-assessment survey and one in a forecaster assessment summary, concerning sensitivity loss and its impact on

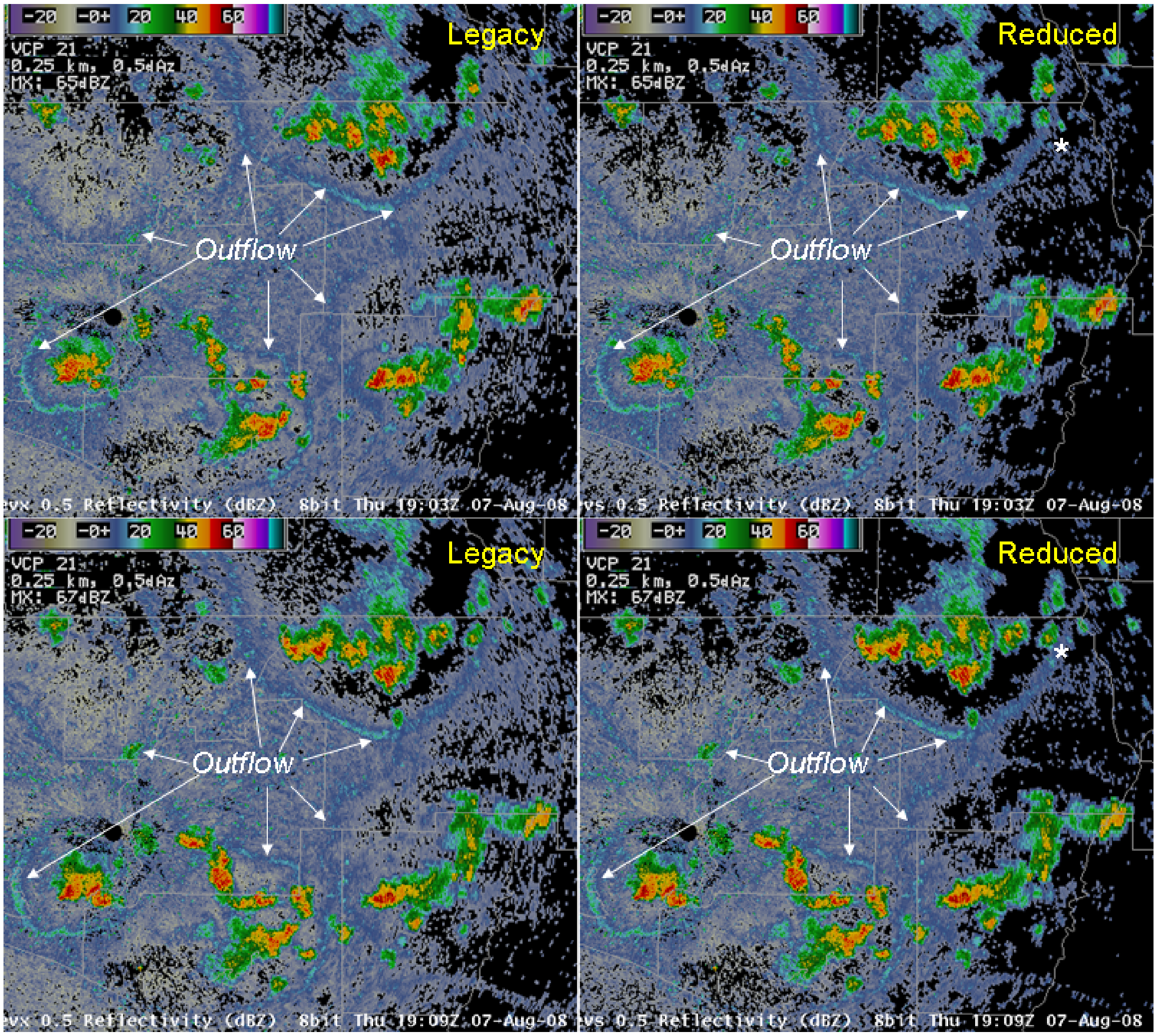

Figure 18: Half degree base reflectivity at legacy (Left Top, Left Middle, Left Bottom) and 4 dB reduced sensitivity (Right Top, Right Middle, Right Bottom) at 1903 and 1909Z for thunderstorms and their associated outflow near Egland AFB, FL, 07 Aug 2008. The white asterisk on the two reduced sensitivity images is at 55nm. There are not much discernible differences close to the radar but outflow is slightly less visible in the reduced sensitivity images at around 50 nm.

light snow and freezing drizzle. Figure 19 shows an example of meso-scale snow bands occurring at the tail end of a mid-Atlantic blizzard on 05 and 06 February, 2010. Once again, the very weak signal, generally less than 5 dBZ at a distance of 100 nm, visible around the periphery of the snow bands in legacy sensitivity is lost with the 4 dB reduction. Nonetheless, the structure and the peak dBZ values of the snow bands are preserved in the reduced sensitivity example. At this distance the impact of this data loss in terms of missed snow accumulation should be fairly limited. We also looked at data from a marginal lake effect snow event over Buffalo, New York between 1102 and 1459Z (image not shown). In this case, there was limited data loss around the periphery of snow echoes at distances over 60 nm from the radar and at reflectivities less than 0 dBZ.

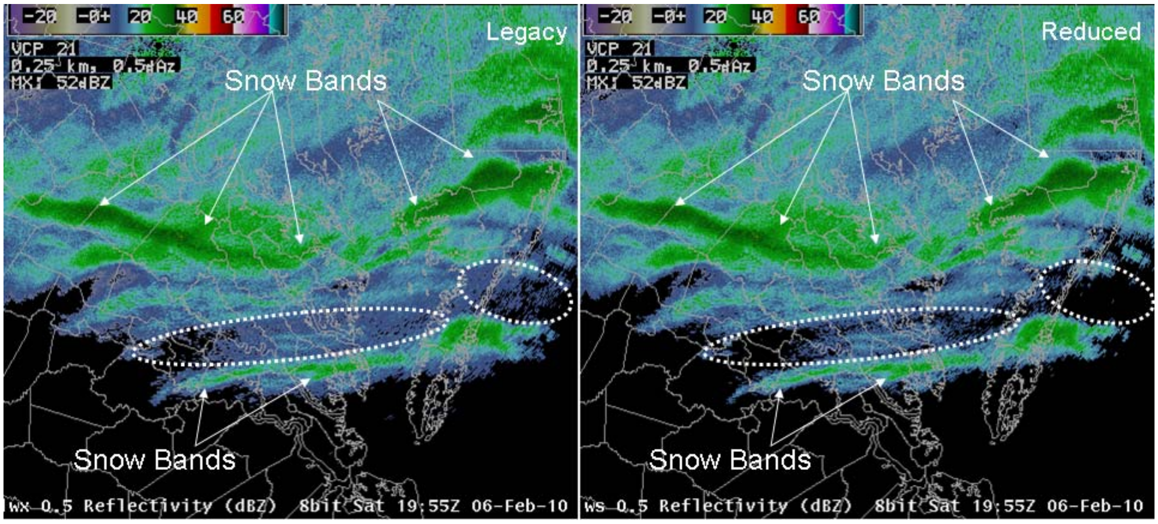

Figure 19: Half degree base reflectivity at legacy, left, and 4 dB reduced sensitivity, right, 1955Z for snow bands southeast of the Sterling, VA radar on 06 February 2010. Only the weakest signal, located on the fringes of the echoes (dashed ovals), are lost in the reduced sensitivity image. The structure and the peak dBZ values within the snow bands are preserved.

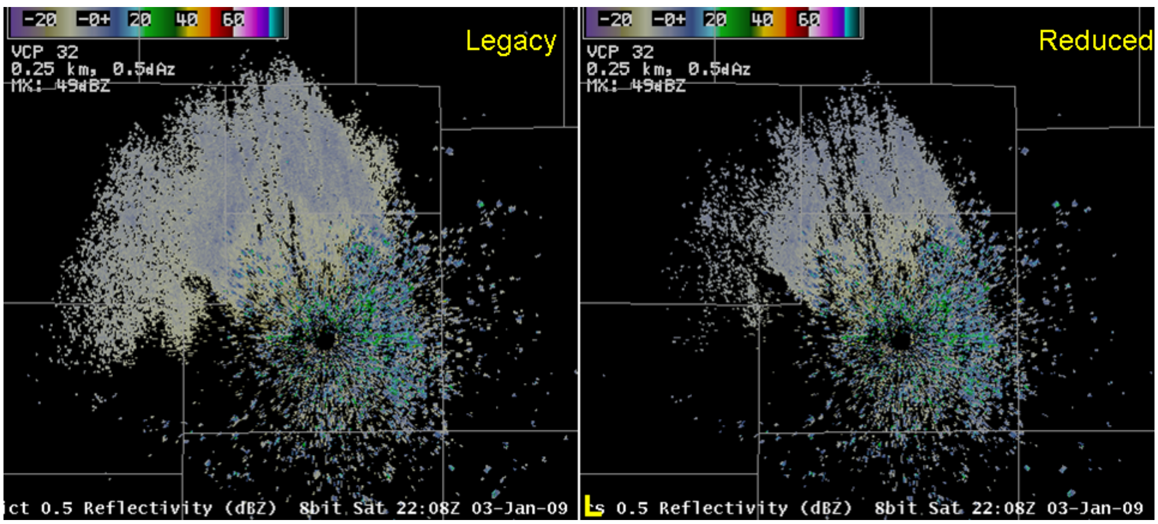

Figure 20: Half degree base reflectivity at legacy, left, and 4 dB reduced sensitivity, right, at 2208Z for freezing drizzle moving into Wichita, KS on 03 Jan 2009. The freezing drizzle had very low reflectivity values; in this example, there is a significant difference between the precipitation coverage seen in the legacy and 4 dB reduced images.

Finally, figure 20 shows an example of freezing drizzle moving into the Wichita, Kansas area. Freezing drizzle is associated with very weak reflectivity values, generally below 0 dBZ. With 4 dB sensitivity removed, there is significant loss of coverage, again on the peripheries of the stronger echoes, in freezing drizzle when compared to the legacy image. However, it is still clear that freezing drizzle is moving into the area, albeit with a smaller aerial coverage than seen in legacy imagery. Training will emphasize that freezing drizzle is going to be the weather hazard most impacted by the sensitivity loss.

In summary, the loss of 3.5 to 4 dB sensitivity due to the DP upgrade will cause a minor loss in data and mostly along the peripheries of stronger echoes. As seen in the Scharfenburg et. al. 2005 study and confirmed with subsequent SME panels, the data loss due to the expected sensitivity reduction is not expected to have a significant impact on forecasting and warning operations. This is substantiated by discussions, surveys and comments from the vast majority (19 out of 20) forecasters who participated in the Operational Assessment. We understand the concern of losing sensitivity in key weather events and have carefully examined any potentially adverse impacts from several events. Our conclusion remains that the benefits provided by the DP data are much greater than the data loss due to the DP upgrade.

5 Summary and Conclusions

The 17-19th August Operational Assessment was convened to have field forecasters to assess the utility of using DP data in operations, to solicit feedback on what they believe are the key benefits and the top challenges they expect to implement the capability. The feedback collected from this event showed forecasters foresee DP significantly increasing the WSR-88D's effectiveness, particularly for Winter Weather and Flash Flood events and to a lesser extent Severe Convection events.

Specifically, forecasters believed Winter Weather WSR-88D DP benefits included DP's ability to 1) explicitly determine the location of the melting layer, 2) to determine the precipitation type and delineate where rain/snow transition zones exist, particularly in areas where spotters or surface observations are sparse, and 3) potentially bring a higher degree of confidence in short term forecasting during winter events. One of the comments explicitly mentioned the potential DP could bring to NWS customers:

"Earlier detection of a possible (precipitation) phase change should also aid in communication with state officials, school districts and street departments. Our increased confidence in precipitation type should also increase their confidence in making decisions to close schools/highways and how many employees to call in for snow removal or road treatment. Increased confidence in precipitation estimates should also aid in decision making for various headlines, especially freezing rain and snow or heavy snow."

Forecasters also believed DP would increase the WSR-88D's effectiveness during Flash Flood forecasting and warning operations. However, it was not just the potential for more accurate precipitation estimates via the DP QPE algorithms. Forecasters also noted the added value for being able to discern between regions with hail mixed with rain vs. regions of mainly heavy rain using the DP base variable products. This helped them to target the areas having the largest threat for flash flooding.

Forecasters foresaw DP increasing the WSR-88D's effectiveness during Severe Thunderstorm events although the increase is of a lower magnitude than that recorded for Winter Weather and Flash Flood operations. Forecasters noted that DP data 1) increased their awareness of where hail was located within storms, 2) helped them distinguish whether or not hail is of extreme size (> 2 inches) and 3) helped them target storms with strengthening updrafts, hence needing closer monitoring. The reason for only a modest increase in the expected effectiveness of the DP WSR-88D for severe convection events is due to a couple of reasons. First, DP radar products at this time cannot differentiate between sub-severe and borderline severe hail. There is currently no DP algorithm sophisticated enough to provide this information. Additionally, forecasters did not see DP products adding value to the prediction or detection of damaging winds.

Forecasters did not believe DP would appreciably change the WSR-88D's effectiveness in tornado warning operations, at least in terms of increasing tornado warning lead time. However, forecasters did note the ability for DP data to confirm the presence of a damaging tornado for storms within ~60 nm of the radar, a great asset at night or in spotter-sparse regions. Forecasters noted this would 1) enhance their situational awareness, 2) provide a more effective way to communicate the confirmation of a damaging tornado to the public via follow-up severe weather statements and 3) help in tornado track analysis for damage surveys.

At the end of the assessment, each forecaster wrote a summary that addressed what they believed were the top DP benefits, implementation challenges and the key DP research areas needed for future development. By far, the top DP benefits noted were 1) the improved ability to pinpoint heavy rain along with the potential for better rain estimates through DP QPE, 2) the improvement in identifying key severe weather features, e.g., discerning hail location, updraft strength and tornado debris locations, and 3) improved knowledge of precipitation type during winter weather events. The top challenges were 1) the need for comprehensive and continuous DP training, 2) integrating and transitioning DP data into operations and the difficulty of developing DP expertise within the office, and 3) the perceived workload increase with the addition of the new DP data. The research areas that forecasters thought were most important for future DP development were 1) refining the DP QPE estimates and 2) developing a method for DP to explicitly discern hail size.

Finally, there were three comments made concerning the 3.5 to 4 dB loss in sensitivity that radars will experience after the DP upgrade. These were made in response to the sensitivity demonstration held on the final day, where key meteorological features were shown at legacy and with a simulated 4 dB reduced sensitivity. One of the comments was concerned about the potential of losing key velocity data while evaluating mesocyclones in supercells. The examples showed that, yes, there would be loss of data in the weak signal areas just outside of the mesocyclone; however, the mesocyclone was still clearly identifiable. The other two comments were concerned with the loss of data during light, dry snow events and freezing drizzle events. With snow, there was not an appreciable loss of data due to the reduced sensitivity. In the example of freezing drizzle, there was some loss of data coverage, due to the sensitivity reduction, that would make it more difficult for a forecaster to detect freezing drizzle as it moves near the radar. However, in the freezing drizzle example shown, it is still clear that an area of precipitation is moving into the area. Forecasters will have to remain vigilant in cases where arctic air moves into an area and freezing drizzle is likely.

APPENDIX A: SENSITIVITY DEMONSTRATION DETAILS

In simulating the reduction of sensitivity we used a method very similar to Scharfenburg et. al., 2005. Specifically, we adjusted the signal-to-noise ratio (SNR) thresholds to remove the data with the lowest 4 dB of power return. The SNR is a function of the reflectivity, the radar slant range and the atmospheric attenuation gradient and can be described in the following equation:

$$SNR\ (dB) = Reflectivity\ (dBZ) - dBZo + (R * A(el)) - 20Log10R$$

where ***dBZo*** is the noise adjusted radar calibration constant, ***R*** is slant range from radar and ***A(el)*** the atmospheric attenuation gradient which is a function of elevation angle. To reduce the sensitivity by 4 dB, we added 4 dB to the Volume Coverage Pattern's SNR threshold and used the following relation to reduce power across the entire data field:

If $\quad SNR\ (db) < (SNR\_T + SL\ (dB))$

Then $\quad M = 0$ ***for any values below*** SNR_T

where '***SL***' denotes the 4 dB Sensitivity Loss desired, '***M***' denotes either the Reflectivity, Velocity or Spectrum Width moment and ***SNR_T*** denotes the Signal-to-Noise Ratio threshold defined for each VCP definition.

APPENDIX B: SAMPLE OF PRE ASSESSMENT SURVEY QUESTIONS

Page 1 - Question 1 - Choice - One Answer (Drop Down)
[Mandatory]

Please select your name from the list of participants (NOT SHOWN IN THIS EXAMPLE):

Page 2 - Question 2 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Please rate the overall effectiveness of the WSR-88D in supporting your interrogation process for a:
Severe Convective threat (wind and/or hail).

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 2 - Question 3 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your experience with using the WSR-88D to assess a Severe Convective Threat (if no experience, enter N/A).
(Comment area allows up to 3,500 characters. Hint: Instead of composing your comments in the provided comment area, you might consider using WORD or some other wordprocessor software to copy/paste your comments into this area.)

(Click on the SUBMIT button to move forward to the next page of questions.)

Page 3 - Question 4 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Please rate the overall effectiveness of the WSR-88D in supporting your interrogation process for a:
Tornado threat.

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 3 - Question 5 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your experience with using the WSR-88D to assess a Tornado Threat (if no experience, enter N/A).
(Comment area allows up to 3,500 characters.)

Page 4 - Question 6 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Please rate the overall effectiveness of the WSR-88D in supporting your interrogation process for: Winter Weather events.

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 4 - Question 7 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your experience with using the WSR-88D to assess Winter Weather impacts (if no experience, enter N/A).
(Comment area allows up to 3,500 characters.)

Page 5 - Question 8 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Please rate the overall effectiveness of the WSR-88D in supporting your interrogation process for a:
Flash Flood threat.

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 5 - Question 9 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your experience with using the WSR-88D to assess a Flash Flood Threat (if no experience, enter N/A).
(Comment area allows up to 3,500 characters.)

APPENDIX C: SAMPLE OF POST ASSESSMENT SURVEY QUESTIONS

Page 1 - Question 1 - Choice - One Answer (Drop Down)
[Mandatory]

Please select your name from the list of participants (NOT SHOWN IN THIS EXAMPLE):

Page 2 - Question 2 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Based on your participation in this assessment, please rate the potential effectiveness that you perceive the Dual-Pol WSR-88D may have in supporting your interrogation process for a:
Severe Convective threat (wind and/or hail).

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 2 - Question 3 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your assessment experience using the Dual-Pol WSR-88D data to assess a Severe Convective threat.

(Comment area allows up to 3,500 characters. Hint: Instead of composing your comments in the provided comment area, you might consider using WORD or some other wordprocessor software to copy/paste your comments into this area.)

(Click on the SUBMIT button to move forward to the next page of questions.)

Page 3 - Question 4 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Based on your participation in this assessment, please rate the potential effectiveness that you perceive the Dual-Pol WSR-88D may have in supporting your interrogation process for a:

Tornado threat.

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 3 - Question 5 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your assessment experience using the Dual-Pol WSR-88D data to assess a Tornado threat.
(Comment area allows up to 3,500 characters.)

Page 4 - Question 6 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Based on your participation in this assessment, please rate the potential effectiveness that you perceive the Dual-Pol WSR-88D may have in supporting your interrogation process for:
Winter Weather events.

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 4 - Question 7 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your assessment experience using the Dual-Pol WSR-88D data to assess a Winter Weather event.
(Comment area allows up to 3,500 characters.)

Page 5 - Question 8 - Rating Scale - One Answer (Horizontal)
[Mandatory]

Based on your participation in this assessment, please rate the potential effectiveness of the Dual-Pol WSR-88D in supporting your interrogation process for a:
Flash Flood threat.

N/A	Completely INEFFECTIVE	2	3	4	5	6	7	8	9	Completely EFFECTIVE
❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Page 5 - Question 9 - Open Ended - Comments Box
[Mandatory]

Please elaborate on your assessment experience using the Dual-Pol WSR-88D to assess a Flash Flood Threat.
(Comment area allows up to 3,500 characters.)

APPENDIX D: SAMPLE OF CASE STUDY SURVEY QUESTIONS

Page 1 - Question 1 - Choice - One Answer (Drop Down) [Mandatory]

Please select your name from the list of participants NOT SHOWN IN THIS EXAMPLE:

Page 1 - Heading

Case being evaluated:
Case 3: 10 May 2010 Tornado Outbreak

Page 2 - Question 2 - Yes or No [Mandatory]

Did the Dual-Pol products enhance your understanding of the conceptual model for this event?

- ❍ Yes [Skip to 3]
- ❍ No [Skip to 4]

Page 3 - Question 3 - Choice - Multiple Answers (Bullets) [Mandatory]

Which Dual-Pol products supported your understanding of the conceptual model?

- ❑ ZDR - Differential Reflectivity
- ❑ CC - Correlation Coefficient
- ❑ KDP - Specific Differential Phase
- ❑ Hydrometeor Classification
- ❑ Other, please specify

Page 3 - Question 4 - Open Ended - Comments Box [Mandatory]

Please comment on how these product(s) contributed to your understanding.

[Skip Unconditionally to 6]

Page 4 - Question 5 - Yes or No [Mandatory]

Did the Dual-Pol products detract from your understanding of the conceptual model for this event?

- ❍ Yes [Skip to 5]
- ❍ No [Skip to 6]

Page 5 - Question 6 - Choice - Multiple Answers (Bullets) [Mandatory]

Which Dual-Pol products detracted from your understanding of the conceptual model?

- ❑ ZDR - Differential Reflectivity

- ❑ CC - Correlation Coefficient
- ❑ KDP - Specific Differential Phase
- ❑ Hydrometeor Classification
- ❑ Other, please specify

____

Page 5 - Question 7 - Open Ended - Comments Box [Mandatory]

Please comment on how the product(s) detracted your understanding.

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____
____

Page 6 - Question 8 - Yes or No [Mandatory]

Did the Dual-Pol products enhance your ability to gain situation awareness of the hazards and impacts with this event?

- ❍ Yes [Skip to 7]
- ❍ No [Skip to 8]

Page 7 - Question 9 - Choice - Multiple Answers (Bullets) [Mandatory]

Which Dual-Pol products helped you gain situational awareness?

- ❑ ZDR - Differential Reflectivity
- ❑ CC - Correlation Coefficient
- ❑ KDP - Specific Differential Phase
- ❑ Hydrometeor Classification
- ❑ Other, please specify

____

Page 7 - Question 10 - Open Ended - Comments Box [Mandatory]

Please comment on how the product(s) contributed.

____
____
____
____

[Skip Unconditionally to 10]

Page 8 - Question 11 - Yes or No [Mandatory]

Did the Dual-Pol products detract from your ability to gain situation awareness of the hazards and impacts with this event?

- ❍ Yes [Skip to 9]
- ❍ No [Skip to 10]

Page 9 - Question 12 - Choice - Multiple Answers (Bullets) [Mandatory]

Which Dual-Pol products detracted from your ability to gain situational awareness of the hazards and impacts with this event:

- ❑ ZDR - Differential Reflectivity
- ❑ CC - Correlation Coefficient
- ❑ KDP - Specific Differential Phase
- ❑ Hydrometeor Classification
- ❑ Other, please specify

Page 9 - Question 13 - Open Ended - Comments Box [Mandatory]

Please comment on how the product(s) detracted.

Page 10 - Question 14 - Yes or No [Mandatory]

Did the Dual-Pol products increase your confidence with respect to determining the threat(s) and potential impacts for this event?

- ❍ Yes [Skip to 11]
- ❍ No [Skip to 12]

Page 11 - Question 15 - Choice - Multiple Answers (Bullets) [Mandatory]

Which Dual-Pol products helped to increase your confidence?

- ❑ ZDR - Differential Reflectivity
- ❑ CC - Correlation Coefficient
- ❑ KDP - Specific Differential Phase
- ❑ Hydrometeor Classification
- ❑ Other, please specify

Page 11 - Question 16 - Open Ended - Comments Box [Mandatory]

Please comment on how the product(s) increased your confidence.

[Skip Unconditionally to 14]

Page 12 - Question 17 - Yes or No [Mandatory]

Did the Dual Pol products reduce your confidence with respect to determining the threat(s) and potential impacts for this event?

- ❍ Yes [Skip to 13]
- ❍ No [Skip to 14]

Page 13 - Question 18 - Choice - Multiple Answers (Bullets) [Mandatory]

Which Dual-Pol products reduced your confidence?:

- ❑ ZDR - Differential Reflectivity
- ❑ CC - Correlation Coefficient
- ❑ KDP - Specific Differential Phase
- ❑ Hydrometeor Classification
- ❑ Other, please specify

Page 13 - Question 19 - Open Ended - Comments Box [Mandatory]

Please comment on how the product(s) reduced your confidence.

Page 14 - Question 20 - Open Ended - Comments Box [Mandatory]

Please comment on any workload impact of including the Dual-Pol products into your decision making methodology.

Page 14 - Question 21 - Open Ended - Comments Box [Mandatory]

Please comment on any strategies that you developed to incorporate Dual-Pol products into your decision making process.

Page 14 - Question 22 - Open Ended - Comments Box [Mandatory]

Please comment on how you anticipate the Dual-Pol products to be integrated into operations at your office.

APPENDIX E: REFERENCES

Scharfenburg, K. A., K. L. Elmore, E. Forren and V. Melnikov, 2005: Estimating the Impact of a 3-dB Sensitivity Loss on WSR-88D Data. 32nd Conf on Radar Meteorology, Albuquerque, NM, Amer. Meteor. Soc.

Technical Report I, 2010: Assessing the Operational Impacts of the Sensitivity Loss Associated With The WSR-88D Polarimetric Upgrade, Report from the Radar Operations Center, 10 pp [Available from NOAA/ROC, 1200 Westheimer Drive, Bldg 375, Norman, OK 73069

Technical Report II, 2010: Second Subject Matter Expert Assessment of Operational Impacts Of The Sensitivity Loss Associated With The WSR-88D Polarimetric Upgrade, Report from the Radar Operations Center, 24 pp [Available from NOAA/ROC, 1200 Westheimer Drive, Bldg 375, Norman, OK 73069

Technical Report III, 2010: Sensitivity Analysis: Comparing the WSR-88D Baseline and L3 Baron Dual Polarization Modification, Report from the Radar Operations Center, 25 pp [Available from NOAA/ROC, 1200 Westheimer Drive, Bldg 375, Norman, OK 73069