Overview *of the* Joint Polarization Experiment (JPOLE)

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CONTENTS

PREAMBLE

     Over the years NSSL has been providing technical information to the National Weather Service. This exchange had many forms, from formal reports and algorithms to consultation and supply of radar data in real time to the Weather Services Forecast Office. After the decision to evolve its network of WSR-88Ds to keep pace with emerging knowledge and technology the NWS provided a spare WSR-88D to NSSL.   Hence, NSSL became the principal NOAA Laboratory for evolutionary and revolutionary enhancements of weather radar science and technology. At that time (mid nineties) Doppler Radar and Remote Sensing Research group committed to document in report form all significant innovations, changes, and results deemed of special value for operational applications regardless weather such writing was formally required. This is the thirteenth report in the series since 1997. It presents an overview of the Joint POLarization Experiment (JPOLE) that lasted from spring of 2002 until summer of 2003. I was fortunate to share the work on polarimetric upgrade of the research and development WSR-88D with scientists and engineers second to none. Allen Zahrai led the team of engineers who designed the new processor which enabled scanning strategies and allowed more flexibility than the old system.   Mike Schmidt ably assisted with Richard Wahkinney made extensive modifications of microwave circuitry and controls.   John Carter contributed to design of microwave circuits and with Valery Melnikov made numerous calibration measurements of the two channels. As always I relied on my colleague Dick Doviak for support, advice, and technical help. Alan Sigia, from Sigmet, resolved numerous technical details needed to operate the RVP7 processor in dual polarization mode. The Radar Operations Center (ROC) of NWS contributed the basic RVP7 processor and display, which was subsequently enhanced to process dual polarization signals.

     This is the first year that NWS's Office of Science and Technology specifically and generously contributed to the dual polarization effort at NSSL. Thus the report represents our continuous commitment to NWS and is part of a cumulative contribution to the Office of Science and Technology.

September 2003 in Norman
Dusan S. Zrnic

1. Introduction

In the spring of 2003, the National Weather Service (NWS) Office of Science and Technology tasked the National Severe Storms Laboratory (NSSL) with providing data collection and analysis to support a WSR-88D dual-polarization decision briefing to the NEXRAD Program Management Committee (NPMC). This decision briefing, which will occur on November 19, 2003, will come at the end of a year long data collection and operational demonstration project, hereafter referred to as the Joint Polarization Experiment (JPOLE). JPOLE was designed to evaluate the engineering design and data quality of the polarimetric KOUN WSR-88D radar and demonstrate the utility of polarimetric radar data and products to operational users. In this report, we describe JPOLE data collection and processing techniques, present an overview of the KOUN data archive, analyze the use of the KOUN data and products by operational forecasters, and present impressions of the utility of the polarimetric upgrade to the WSR-88D radar.

Complementary reports will examine KOUN data to demonstrate polarimetric radar's ability to improve Quantitative Precipitation Estimates (Ryzhkov et al. 2003), and to discriminate between hydrometeor types and improve data quality through the elimination of non-meteorological artifacts (Schuur et al. 2003a).

1.1 JPOLE goals

The overarching goals of JPOLE were to test the engineering design and determine the data quality of the polarimetric KOUN WSR-88D radar, demonstrate the utility and feasibility of the radar to operational users, and collect data and information that could be used to perform a cost/benefit analysis.

1.1.1 Engineering design and data quality

Unlike most research polarimetric radars, the polarimetric KOUN WSR-88D radar employs a simultaneous horizontal/vertical transmission scheme (Doviak et al. 2000). While simultaneous transmission is expected to have many practical advantages over the more common alternate horizontal/vertical transmission scheme, it remains largely untested. JPOLE therefore provided an opportunity to evaluate critical engineering and data quality issues. For example, radar data quality was assessed through a comparison with verification datasets, the radar scanning strategy evaluated to assess compatibility with requirements of the existing WSR-88D radar system, and the simultaneous transmission mode examined to calibrate polarimetric radar measurements, establish and verify engineering specifications, and investigate short and long term stability. More specifically, the engineering design and data quality objectives of the operational demonstration were to

- Demonstrate the accuracy of KOUN reflectivity, velocity, and spectrum width measurements
- Demonstrate that polarimetric precipitation estimation and hydrometeor classification products can be collected with acceptable antenna rotation rates (all previous research results were obtained with relatively slow scan strategies)
- Perform tests to ensure minimal degradation in VCP times, and no degradation in ground clutter filtering, anomalous propagation filtering, and velocity dealiasing
- Evaluate the value of alternate ρ_{HV} and L_{DR} scans (and limits to any of the variables)

Melnikov et al. (2003) provides a detailed engineering evaluation of the calibration and performance of the polarimetric KOUN WSR-88D radar. This report, and the complementary reports of Ryzhkov et al. (2003) and Schuur et al. (2003a) will further address data quality issues.

1.1.2 Benefits to operational users

JPOLE also provided an opportunity to examine the benefits of polarimetric radar data to operational users. During JPOLE, KOUN data and products were delivered to operational forecasters at the Norman, Oklahoma NWS office. NSSL scientists then assisted the forecasters in the analysis and use of the polarimetric data and products. Post-event questionnaires were then filled out by the forecasters to gauge their impression of the use of polarimetric data in the warning decision process. Specifically, the product performance evaluation objectives were to evaluate the ability of the polarimetric data to

- Improve Quantitative Precipitation Estimation (QPE)
- Improve operational hydrologic forecasts (especially for flash flood events)
- Discriminate hail from rain and gauge hail size
- Identify precipitation type in winter storms (dry/wet snow, sleet, rain)
- Identify biological scatterers (and their effects on the wind measurements)
- Identify the presence of chaff (and its effect on precipitation measurements)
- Identify areas of ground clutter and anomalous propagation
- Detect polarimetric signatures of tornado debris

Recent papers by Scharfenberg et al. (2003), Scharfenberg and Maxwell (2003), and Miller and Scharfenberg (2003) provide examples of how polarimetric data and products were used in the warning decision process. This report will provide additional discussion of the operational use of the polarimetric KOUN data and products, and an analysis of the forecaster survey and comments.

1.1.3 Economic benefits

A final goal of JPOLE was to provide research and analysis that could be used to conduct a cost/benefit study and to demonstrate the economic benefits provided by a potential national network of polarimetric WSR-88D radars. The possible economic benefits of such a network are substantial. For example, improved detection of non-meteorological echoes has the potential to greatly enhance data quality, improve rainfall accumulation estimates and water resource management capabilities, and improve the detection of precipitation type and transportation administration capabilities (through, for example, airspace recovery times and highway closures). These and other economic benefits are summarized in the NPMC briefing, which is being prepared by the NWS Office of Science and Technology. The complementary reports of Ryzhkov et al. (2003) and Schuur et al. (2003a) describe the research in support of this cost/benefit study.

2. Overview of JPOLE operations

During JPOLE, radar data from the NSSL Cimarron polarimetric radar and standards NWS KTLX, KINX, KVNX, and KFDR WSR-88D radars, as well as rain gage data from the Oklahoma Climate Survey (OCS) mesonet and Agricultural Research Service (ARS) micronet, were collected to be used as verification datasets for the polarimetric WSR-88D analyses. These facilities, and their locations with respect to the KOUN radar, are shown in Figure 1.
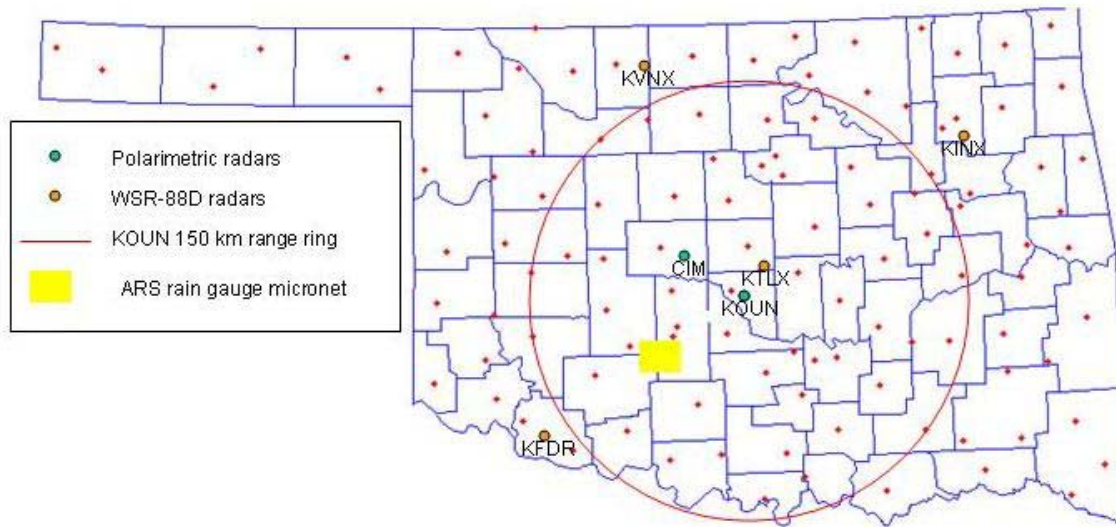
Figure 1: JPOLE observational facilities. Green dots depict locations of the polarimetric KOUN WSR-88D, NSSL Cimarron radars. Orange dots depict locations of conventional KTLX, KINX, KVNX, and KFDR WSR-88D radars. Red dots indicate locations of the 115 Oklahoma mesonet rain gauges and yellow box the location of 42 gauge ARS micronet. Red circle shows 100 km range ring for the KOUN radar.

In this section, we discuss KOUN data collection. Verification datasets are discussed later in this report.

2.1 Data collection/delivery by the polarimetric NSSL Cimarron radar

In preparation for the full WSR-88D radar test, the NSSL began to introduce polarimetric radar data and products from the NSSL Cimarron polarimetric radar to operational forecasters at the Norman, Oklahoma NWS Forecast Office in the spring of 2001. Due to mechanical limitations of the Cimarron pedestal, it was only possible to collect data at 0.0°, 0.5°, and 1.0° and a maximum rotation rate of 6°/s. Nevertheless, the occasional delivery provided operational forecasters, with the assistance of an NSSL observer, an opportunity to familiarize themselves with polarimetric data and products, and the use of those data and products in the warning decision process. Data and products delivered included radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), differential phase (Φ_{DP}), specific differential phase (K_{DP}), and a hydrometeor classification product.

Note that the Cimarron radar transmits an alternate sequence of horizontally and vertically polarized waves. Consequently its polarimetric variables are not exactly equivalent to the polarimetric variables obtained via the simultaneous scheme on the KOUN. Therefore it was important to determine if there would be detrimental differences between the two schemes.

2.2 Data collection/delivery by the polarimetric KOUN WSR-88D radar

2.2.1 Early JPOLE data collection/delivery

In the spring of 2002, the polarimetric upgrade to KOUN WSR-88D radar was completed. At that time, the data feed for the operational delivery was switched from Cimarron to KOUN and a polarimetric radar training seminar was prepared and delivered to the NWS forecasters (a growing data base of case studies available for forecaster training has also since become available on the WWW at: http://cimms.ou.edu/~kscharf/pol/). Much effort during the first few months of data collection was devoted to addressing calibration issues, improving the delivery system, and resolving a severe interference problem with a Federal Aviation Administration training radar located near Will Rogers Airport in Oklahoma City, OK. After approximately 3 months of evaluation and testing, the first high-quality, dataset was delivered to the NWS on 16 June 2002. This dataset, of an areally extensive MCS that exhibited high winds, heavy rainfall, and large hail, is discussed by Schuur et al. (2003b). Because Volume Coverage Patterns (VCPs) that included higher elevation angles had not been developed yet, all data during this early JPOLE data collection/delivery period were collected with VCPs that included only 0.0°, 0.5°, 1.0°, 1.5°, and 2.5° base scans (although with a much faster 20°/s scanning rate than was possible with the Cimarron radar).

Through the summer and fall of 2002, work continued to improve data quality, enhance algorithm performance, and streamline the real-time data processing and delivery system. From the early data collection, it had become apparent that it was difficult to maintain an accurate reflectivity calibration. Through comparison with verification datasets, much data analysis time was therefore devoted to developing techniques to assure higher-quality calibration. The real-time hydrometeor classification algorithm was modified to include corrections for differential attenuation and the hydrometeor classification algorithm upgraded to include winter precipitation products. Several real-time polarimetric rainfall accumulation (1-hour, 3-hour, and storm-total $R(Z)$, $R(Z, Z_{DR})$, $R(K_{DP})$, and $R(K_{DP}, Z_{DR})$) estimates were also developed and added to the suite of algorithms. Summaries of the rainfall accumulation and hydrometeor classification analyses are presented by Ryzhkov et al. (2003) and Schuur et al. (2003a).

Fairly regular real-time data delivery to the NWS began in the fall of 2002. Polarimetric KOUN data collected during several widespread precipitation events in the early fall proved to be useful in the estimation of rainfall accumulation at far ranges. In one event that occurred from 18-20 October, 2002, the forecaster noted that $R(K_{DP})$ estimates in far southeastern Oklahoma matched the Mesonet rainfall accumulations so well that he had greater confidence that flooding was not a serious problem and that it was safe to spend more time monitoring and updating other aviation and public forecast products. Polarimetric KOUN data collected during several winter precipitation events also proved useful in the warning decision process. In depth analyses of several winter precipitation events are presented by Scharfenberg and Maxwell (2003), and Miller and Scharfenberg (2003).

2.2.2 The JPOLE Intense Observation Period

In the spring of 2003, plans were made to conduct a more extensive JPOLE Intense Observation Period (IOP). During the IOP, emphasis was placed on providing uninterrupted data delivery to operational forecasters, obtaining more extensive forecaster feedback on the use of the polarimetric data in the warning decision process, and collecting high-quality verification datasets that could be used to assess the KOUN radar data and product quality. The JPOLE IOP was conducted from March 15, 2003 through June 15, 2003.

During the IOP, KOUN data collection was designed to more closely resemble that of a standard WSR-88D radar. That is, whereas most data prior to the IOP had been collected with VCPs that only included low-elevation surveillance scans, VCPs used during the IOP were designed to, as much as possible, emulate the elevation angles, scanning rates, and volume coverage times of the standard WSR-88D VCP 11 (the VCPs used during the IOP are described in detail in Section 3.2 and Appendix A). A greater emphasis was also placed on the collection of verification datasets. Hail data were collected by two hail intercept vehicles that were deployed to locations where the polarimetric hydrometeor classification algorithm was indicating hail. In-situ cloud microphysics data were collected by the South Dakota School of Mines and Technology T-28 aircraft, which was participating in an electrical study that coincided with the final month of the IOP.

The insight of operational forecasters is vital to the evaluation of WSR-88D radar products. During the IOP, a greater emphasis was therefore placed on forecaster interactions. To obtain more feedback, NSSL observers were scheduled to assist NWS forecasters in the analysis and interpretation of the polarimetric radar data and products for each event that occurred during the 3 month JPOLE IOP (NSSL observers assisted NWS forecasters on a much more irregular basis during the early data collection/delivery phase of JPOLE data collection). After each event, feedback and forecaster comments were then obtained from evaluation forms, which were designed to determine the usefulness and performance of each polarimetric measurement and product. This information would then be used by scientists to improve algorithm performance.

3. Data collection, processing, and delivery

3.1 The polarimetric KOUN WSR-88D radar

The polarimetric KOUN WSR-88D radar was configured from several autonomous subsystems, most of which were not specifically designed for the project. First, a manufacturer was contracted to design and build a custom frequency offset generator that produced intermediate frequency (IF) signals that differ from the existing IF. This hardware was installed and connected to the Sigmet RVP7 processor, which requires the two offset IF signals. The Sigmet processor was then connected in a passive mode to the radar and software developed to transfer Sigmet data onto the local area network so that it could be further manipulated to produce hydrometeor classes and rain amounts. The polarization scheme uses simultaneous transmission and reception of horizontally and vertically polarized echoes. Because it had not been tested, much time was devoted to engineering evaluation and calibration. The calibration and performance of the polarimetric KOUN WSR-88D radar is discussed in great detail by Melnikov et al. (2003). In the following section, we describe real-time KOUN data collection, processing, and delivery to operational forecasters

3.2 Volume Coverage Patterns

During JPOLE data collection, the KOUN radar was controlled by the NSSL Research Radar Data Acquisition (RRDA) unit and the data processed by the Sigmet RVP7 processor. In its passive mode, the Sigmet RVP7 processor was not capable of transferring the data for further processing, primarily to compute rainfall and classification products, until after an entire volume had been completed (the Sigmet RVP8 processor, which is scheduled for installation in the fall of 2003, will allow data to be transferred radial by radial). This limitation, how it was addressed, and its affect on the data delivery, is also discussed. All PPIs listed here were designed to collect Z, Z_{DR}, ρ_{HV}, Φ_{DP}, velocity, and spectrum width. In order to evaluate the value of alternate ρ_{HV}

and LDR scans, RHIs were designed for both simultaneous (Z_{DR}) and horizontal-only (LDR) transmission modes.

3.2.1 PPIs

HYBRID

The HYBRID VCP was designed to emulate the elevation angles, scanning rates, and volume coverage times of the standard WSR-88D VCP 11. Because the Sigmet RVP7 signal processor did not allow multiple PRFs to be used in the same volume, the HYBRID VCP was actually designed to consist of two separate VCPs: HYBRID_A for the lowest 3 elevations, and HYBRID_B for the highest 12 elevations. The low PRF (446 Hz) used by HYBRID_A allowed for long-range surveillance and rainfall estimation over a large area; the high PRF (1013 Hz) used by HYBRID_B provided a faster scanning rate than was possible at the lower elevation angles. This design had the added benefit of significantly reducing the time required to deliver base data and products to operational forecasters. This time savings was found to be critical for fast-evolving warning situations.

The HYBRID VCP is summarized in Appendix A (Table 1). Most of the JPOLE dataset was collected using this HYBRID scanning strategy.

CONVECTIVE

The CONVECTIVE VCP was designed for data collection when intense convective storms were located within 150 km of the radar. It used the same elevations as the HYBRID VCP, but collected all data with a PRF of 1013 Hz. This provided a higher Nyquist velocity for the detection of severe wind events and a faster volume update time than was possible with the HYBRID VCP.

The CONVECTIVE VCP is summarized in Appendix A (Table 2).

TORNADO

The TORNADO and TORNADO_1 VCPs (with 3 and 5 elevations, respectively) were designed to provide rapid, low-level updates for nearby tornadic events. Each VCP used a PRF of 1281 Hz and 64 data samples, which can be compared to the 48 data samples used by the HYBRID and CONVECTIVE VCPs. This gave high quality polarimetric data with volume update times, of 75 and 125 seconds, respectively.

The TORNADO and TORNADO_1 VCPs are summarized in Appendix A (Tables 3 and 4).

3.2.2 RHIs

Z_{DR}

Three RHIs were designed for the simultaneous transmission mode. These RHIs, referred to as RHI_1, RHI_2, and RHI_3, are summarized in Appendix A (Tables 5, 6, and 7). All RHIs use a PRF of 1013 Hz. RHI_1 and RHI_2 each have eleven, 0° to 50° elevation cuts that were centered about a user-defined center azimuth (with a 1°

azimuthal separation between each cut). The elevation resolution of RHI_1 was 1.0°, to give a volume execution time of 160 s; the elevation resolution of RHI_2 was 0.5°, to give a volume execution time of 249 s. RHI_3 is similar to RHI_2 in that it also has an elevation resolution of 0.5°, but it only has seven, 0° to 30° elevation cuts. This allowed for the collection of high-resolution RHI with a much faster volume execution time of 105 s.

LDR

To evaluate the value of alternate ρ_{HV} and LDR scans, RHIs were also designed for the horizontal-only (LDR) transmission modes. Other than being collected in horizontal-only rather than simultaneous transmission mode, thereby allowing LDR to be measured rather than ρ_{HV}, RHI_4, RHI_5, and RHI_6 are completely analogous to RHI_1, RHI_2, and RHI_3 in every respect. These LDR RHIs are summarized in Appendix A (Tables 8, 9, and 10).

3.3 The data delivery system

3.3.1 Overview of the delivery system

Data collection, processing, and product generation was based on the robust design of the WSR-88D radar system. Physically separate computers were designated for each individual function. After receiving raw data from Sigmet, raw data archival and storage was performed by a machine named "Porter", and product generation, serving, and archival by a machine named "Stout". The data and products were then transferred over a Local Area Network connection to any number of machines, where they could be displayed with the NSSL Warning Decision Support System – Integrated Information (WDSS-II; Hondl, 2003). This flexible design closely resembled the WSR-88D system with the RDA being analogous to the combination of Sigmet and Porter, the ORPG being analogous to Stout, and the display machines being analogous to AWIPS. Any number of machines could be used to generate products or to independently view the products that had been generated. If necessary, this allowed NSSL to add computers for algorithm generation and further allowed the distribution of generated products to any number of end users.

3.3.2 Design of the delivery system

After data collection, a remote process on the Sigmet machine transferred data to Porter over the 100 mb NSSL network. It was then loaded into a Linear Buffer (Jing and Jain, 2000) system for distribution to the algorithm machine. The Linear Buffers system then notified the pre-processor algorithm on Stout. The pre-processing algorithm on Stout retrieved the raw Sigmet data, converted it to a fully expanded internal format, calculated the Signal to Noise Ratio, and added corrections to the polarimetric moments. Finally, the pre-processor computed K_{DP} and applied filters to the data to improve data quality. The pre-processor then wrote the 6 quality-controlled dual-polarimetric moments to a linear buffer.

Product generation routines were created to convert the internally formatted data into standard displayable NetCDF files. The standard product generation routine collected data from the linear buffer system as it was generated. At the end of an elevation, it created a NetCDF file and an entry into the product index. Using WDSS-II, the user could then view the file on their computer.

3.3.3 Description of the data archival process

After data collection, a number of Perl scripts were used to archive the raw Sigmet format data to either a CD or a DVD. Up to 6 months of data were also kept on-line for easy access by researchers, testing, and algorithm development. Similarly, processed product data were written to either a CD or a DVD and an index created so that WDSS-II could locate and display the data for the user. The raw Sigmet data were made available in a format similar to Universal format, while the product data were made available in NetCDF format. The product data is viewable using WDSS-II or any other NetCDF viewer.

3.4 Real-time data on the WWW

Because WDSS-II display systems were not available to all users, real-time images of several polarimetric KOUN measurements and products were also generated and displayed on the WWW. This included 0.5° elevation images of Z, Z_{DR}, ρ_{HV}, Φ_{DP}, K_{DP}, velocity, and results of the Hydrometeor Classification Algorithm (HCA), one-hour rainfall accumulations from the polarimetric $R(Z)$, $R(Z, Z_{DR})$, $R(K_{DP})$, and $R(K_{DP}, Z_{DR})$ algorithms (and a comparison to the results of the NWS KTLX WSR-88D $R(Z)$ rainfall accumulation algorithm), storm total precipitation accumulations from the polarimetric $R(Z)$, $R(Z, Z_{DR})$, $R(K_{DP})$, and $R(K_{DP}, Z_{DR})$ algorithms, and a comparison of KOUN and KTLX reflectivities and velocities. The WWW addresses for these data and products are as follows:

> **Base data and HCA product:**
> http://www.nssl.noaa.gov/users/hondl/public_html/radar/koun.html
> **One-hour rainfall products:**
> http://www.nssl.noaa.gov/users/hondl/public_html/radar/koun2.html
> **Storm total rainfall products:**
> http://www.nssl.noaa.gov/users/hondl/public_html/radar/koun_stp.html
> **KOUN-KTLX comparisons:**
> http://www.nssl.noaa.gov/users/hondl/public_html/radar/koun_ktlx.html

One-hour loops of several of the base data measurements were also available on the WWW.

4. The JPOLE data archive

4.1 KOUN data

The KOUN data archive contains an unprecedented collection of meteorological and non-meteorological events observed by polarimetric radar. In total, 98 events were catalogued both chronologically and by event-type, and subsequently described within an online database at http://cimms.ou.edu/~heinsel/jpole/database.html and http://cimms.ou.edu/~heinsel/jpole/stormtype.html, respectively. This archive includes several significant hazardous weather events, including two consecutive tornado outbreaks in the Oklahoma City area, several non-tornadic supercells, a severe storm that produced up to 5" diameter hail, a 20" snowfall over Ponca City, and a nighttime flash flood event in Norman (Table 11). The database also provides a unique opportunity to examine the accuracy and skill of NSSL's polarimetric rainfall estimation and hydrometeor classification algorithms on storms having significant economic and societal impacts. Furthermore, since the tornadic outbreaks occurred within 50 km of KOUN, this dataset sets the stage for studying the potential use of polarimetric signatures to improve tornado warning lead time. The KOUN database also contains many seasonal rainfall events, such as convective cells, warm- and cold-season stratiform precipitation, MCSs, rainbands, mixed precipitation, and

snow (Table 11). This archive supplies the data needed to demonstrate the advantages of using polarimetric hydrometeor classification and rainfall estimation algorithms in NWS and other weather-sensitive operations.

A variety of non-meteorological phenomena were observed also by KOUN, including anomalous propagation, birds, insects, and chaff. Many of these non-meteorological phenomena were measured by KOUN in clear air conditions (15 events), whereas others were associated with precipitation (31 events). Non-meteorological phenomena associated with precipitation may be embedded within precipitation, may correspond with density currents, or occur behind a squall line. This archive provides ample data to establish the efficacy of the dual-polarimetric-based hydrometeor classification algorithm in identifying and mitigating the effects of ground clutter, anomalous propagation, and biological scatterers.

4.2 Rain gage data

Evaluation of polarimetric rainfall estimates is critical to the success of the JPOLE operational demonstration. During JPOLE, rainfall data from three rain gauge networks will be used to evaluate the accuracy of KOUN polarimetric rainfall algorithms at three different spatial scales. These networks include:

4.2.1 The Oklahoma Climate Survey mesonet

The Oklahoma Climate Survey (OCS) mesonet consists of 115 instrumented sites located throughout the state of Oklahoma. The average gauge spacing of this network is approximately 30 km. Data from the mesonet is used to evaluate rainfall accumulation on the mesoscale, rainfall estimation errors at long-distance, and errors resulting from bright band contamination. Access to real-time mesonet data will be available through the NSSL. Quality-controlled data for analysis, however, must be purchased from the OCS.

4.2.2 The Agricultural Research Service micronet

The United Sates Department of Agriculture / Agricultural Research Service (USDA/ARS) micronet consists of 42 instrumented sites over the Little Washita watershed. The center of the micronet is about 70 km from the KOUN radar. The average gauge spacing is approximately 5 km. Data from this network, which is available for the entire JPOLE evaluation period, is used by Ryzhkov et al. (2003) to evaluate polarimetric rainfall estimates for spatial scales typical of a watershed.

4.3 Hail data

4.3.1 Hail chase operations and nowcast support

One goal of the project was to document and verify advantages of dual-polarimetric hail classification compared to operational, single-polarimetric probabilistic hail products. To accomplish this goal, two hail intercept vehicles were available from 28 April through 13 June 2003. During the course of the project, the cars were staffed by volunteer University of Oklahoma students and two members of the Operational Demonstration team. The purpose of the hail chase effort was to intercept thunderstorm cores that had the potential to produce hail at the surface. Observations from the chase teams were compared with KOUN Hydrometeor Classification Algorithm output at low levels to verify the algorithm's ability to discriminate between rain and hail.

One or both vehicles were deployed on eight occasions. On two of those occasions (15-16 May and 12-13 June), hail-producing thunderstorms did not approach near enough KOUN radar for useful data to be collected. On one date (8 May), the target storm could not be safely intercepted due to an accompanying tornado threat in the Oklahoma City Metropolitan area. On the five other dates (30 April, 14 May, 19-20 May, 10-11 June, and 11-12 June) intercepts of hail cores and potential hail cores were made within KOUN range. During the five intercept days, more than 28 hours of data were collected.

Participants were asked to log the following information if:

- The time hail fall began and ended
- The time hail was first observed on the ground
- The time hail was last observed on the ground
- Average and maximum hail diameter, plus whether the sizes were measured, estimated in hand or estimated visually
- Hail shape (sphericity)
- Any spikes or lobes present on the hail
- Amount of rain mixed with falling hail
- Concentration of hail (sporadic, light, moderate, or heavy)
- Hardness of hail (slushy, hard, or mixed)
- Relevant storm features (intense lightning, nearby tornado, high winds, etc.)
- Significant temporal/spatial changes in any of the above.

The vehicles were equipped with Global Positioning System satellite receivers, connected to laptop computers running mapping software. The GPS coordinates and times were logged to the laptop, so the above observations could be later mapped and compared to KOUN data. The vehicles were then directed via telephone by a "nowcaster" stationed at the NSSL, who viewed KOUN data in real time using WDSS-II. Nowcast duties rotated among the four members of the Operational Demonstration team who were not responsible at the time for the operational demonstration at the WFO. The nowcaster notified chase team participants via e-mail the afternoon before an expected "chase day" that operations were possible. The nowcaster continued monitoring the weather situation and keeping the chasers updated until a decision to launch the vehicles or cancel the mission. Such decisions were often made in coordination with WFO forecasters and the person responsible for that day's WFO operational demonstration.

After the vehicles were launched, the nowcaster directed the vehicles toward potential hail cores within 100-150 km of KOUN. Often, this meant sending the cars in different directions to intercept different storms. Preference was given, when possible, to storms nearer the radar and to storms moving toward the radar. Observations of hail greater than 0.75 inches in diameter were relayed to WFO forecasters by the nowcaster in real time.

4.3.2 Hail archive and analysis procedures

The dataset incorporates several storm types, such as isolated severe (1 May 2003), high-precipitation, classic, and low-precipitation supercells (14 May 2003, 19-20 May 2003, and 11−12 June, respectively), and a squall line (10−11 June 2003). Hail size ranged from about 10 mm to 127 mm, with the largest hail reported on 14 May 2003, in association with the high-precipitation supercell. Ground truth reports were checked for spatial and temporal discrepancies by overlaying them on corresponding PPIs of 0.5° KOUN reflectivity data objectively analyzed in Cartesian coordinates. Reports retained for analysis occurred within 6 minutes of the radar

time stamp and were located within a selected radius of influence from the 40 dBZ contour. The radius of influence is defined as the average distance the storm traveled between 6 min volume scans, and varied from 3.2 to 5.4 km. This procedure resulted in 50 hail and 23 rain ground truth observations.

4.4 Supplemental datasets

4.4.1 Airborne measurements

From May 12, 2003 through June 12, 2003, the South Dakota School of Mines and Technology (SDSMT) storm-penetrating T-28 aircraft, as part of a separate field project that was designed to storm electrification and lightning, collected in-situ microphysical data in several storms that were being sampled by the polarimetric KOUN radar. These microphysical data are available from Dr. Andy Detwiler of SDSMT.

4.4.2 Surface observations

Surface observations for JPOLE analyses were obtained from the 115 station OCS mesonet, with sites located throughout the state of Oklahoma. Access to real-time mesonet data was available through NSSL, though quality-controlled data for analysis must be purchased from the OCS. NWS surface observations are also available for analysis.

5. Operational Demonstration

In this section we evaluate the use of the polarimetric KOUN data and products by operational forecasters at the Norman, OK NWS during the JPOLE IOP. End-of-shift and End-of-project questionnaires that summarize forecaster evaluations and comments are included in this report as Appendix C and Appendix D, respectively.

5.1 Forecaster training

Web-based training pages and case studies were made available to WFO forecasters on 1 April. These pages are available at http://www.cimms.ou.edu/~kscharf/pol. These materials were also added as an appendix to the JPOLE Operational Demonstration Operations Plan. The following training pages and cases studies were developed and made available to forecasters on the internet and as an appendix to the Operations Plan:

- Polarimetric radar overview
- Differential Reflectivity (Z_{DR}) primer
- Specific Differential Phase (K_{DP}) primer
- Correlation Coefficient primer
- Hydrometeor Classification Algorithm (HCA) primer
- Quantitative Precipitation Estimation (QPE) algorithms primer
- 15-16 June 2002 mesoscale convective system KOUN case study (included beam attenuation)
- 18-19 September 2002 severe thunderstorms (included multiple hail-producing thunderstorms)
- 12 March 2003 thunderstorms (included multiple hail-producing thunderstorms)
- WDSS-II users guide (appendix to operations plan only)

5.2 Description of the operational demonstration

KOUN data were successfully delivered to the WFO for about 480 hours between 15 April and 15 June. An NSSL representative was at the WFO for at least a portion of the event on 22 separate days of delivery. The data were viewed at the WFO on two Linux workstations that ran the NSSL Warning Decision Support System – Integrated Information (WDSS-II) software package. NSSL observers assisted the forecasters in the use of the WDSS-II system and the interpretation of the polarimetric data and products. One of the Linux workstations was located adjacent to the primary warning forecaster position in the operations area, and the second was located on an outer wall of the operations area. The workstation that was adjacent to the primary warning area was used by the NWS forecaster, whereas the workstation along the wall of the operations area was primarily used by the NSSL representative/observer. During severe events, the NSSL representative would observe the event, and update the lead forecaster on any polarimetric signatures and products that he/she felt might be useful in the warning decision process.

The NSSL meteorologist assigned to the WFO operational demonstration was asked to perform the following duties:

- Monitor the weather situation and coordinate radar usage with KOUN operators and WFO forecasters
- Record instances of KOUN data integration into WFO operations
- Note polarimetric characteristics in supercells (tornado debris signatures, hail core detections, "Z_{DR} column" updraft detections, rain accumulation estimates, etc.)
- Note QPE algorithm performance in potential flash flood situations
- Note data quality issues (HCA discrimination of AP, bird, insects, and clutter, and any radar calibration issues)
- Give "on-the-fly" training to forecasters on polarimetric theory, signatures, and WDSS-II
- Pass along to WFO forecasters relevant observations
- Assist WFO staff in making verification calls to storm spotters and chasers

5.3 Data delivery events

Several significant and noteworthy severe weather events occurred during the operational demonstration. An NSSL meteorologist was at the WFO during major parts of each event. These events included:

- 23-24 April – Significant mesoscale convective system with damaging bow echo
- 30 April-1 May – Numerous hail-producing thunderstorms
- 8 May (am) – Strong supercells that produced very large hail and several tornadoes in southern Oklahoma.
- 8 May (pm) – Strong supercell with F4 tornado in Moore and Choctaw
- 9-10 May – Numerous strong supercells with large hail. Family of tornadoes, producing up to F3 damage, in Oklahoma City metropolitan area.
- 10 May (pm) – Numerous hail-producing thunderstorms.
- 14 May – Train of strong supercells that produced very heavy rain and giant hail up to 13 cm in diameter.
- 16 May – Strong mesoscale convective system.
- 19-20 May – Numerous hail-producing thunderstorms

- 24-25 May – Numerous hail-producing thunderstorms
- 11-12 June – Hail-producing supercells that evolved into damaging mesoscale convective system.

An overview of the 8 May, 9-10 May, and 14 May events was presented at the 31st International Conference on Radar Meteorology in Seattle, Washington in August 2003. During large hail events, the NSSL meteorologist helped WFO forecasters narrow down the hail threat spatially using KOUN data. Polarimetric data were used in hail forecasting and warnings for dozens of storms during the operational demonstration. In addition, NSSL meteorologists aided in the identification and interpretation of "Z_{DR} columns" – or regions of high Z_{DR} extending above the ambient melting level, locating regions of enhanced convective updrafts. Finally, the NSSL meteorologists aided forecasters in the interpretation of the polarimetric QPE algorithms during periods when heavy rain accumulation was a concern.

5.4 Forecaster evaluations

After each severe weather event, forecasters who used KOUN data extensively were given "post-shift" evaluation forms. At the end of the operational demonstration, anyone who filled out a "post-shift" form was given an "end-of-project" evaluation form. Forecasters unanimously agreed the polarimetric data were a valuable addition to operations. The polarimetric QPE algorithms received high marks, and in several cases, forecasters said these algorithms were used specifically in the decision not to issue flash flood warnings in regions where the traditional Z/R rainfall accumulation algorithms were inflated.

Forecasters were very comfortable understanding and using the Z_{DR} field. Several used Z_{DR} to identify regions of enhanced hail threat and regions of supercooled water above the melting level in updrafts. Forecasters had a little more difficulty interpreting the K_{DP} field, and had the least understanding of Correlation Coefficient. Forecasters showed a great deal of confidence in the Hydrometeor Classification Algorithm output, particularly regarding the discrimination between rain and hail, and between precipitating and non-precipitating scatterers.

Several forecasters expressed reluctance to use the WDSS-II workstation, due either to earlier bad experience with WDSS-II, lack of time, and/or lack of available staff. Many others suggested the ability to view KOUN products at their AWIPS workstations would increase the likelihood and frequency of their use of these data.

5.5 Summary of survey results

A total of seven post-shift evaluation forms were received after warning operations. All respondents either agreed or strongly agreed the following were a positive contribution to the warning process during their shift:

- The Hydrometeor Classification algorithm
- The QPE rate and accumulation algorithms
- Polarimetric base products such as Z_{DR} and K_{DP}
- KOUN polarimetric WSR-88D radar as a whole

A total of six end-of-season evaluation forms were also received. Respondents rated KOUN and various products on a zero to five scale, with a score of five representing best

performance. These average scores refer to the overall usefulness of the tool in warning and "nowcasting":

- Hydrometeor Classification Algorithm - 3.875.
- Polarimetric QPE accumulation algorithms - 4.8.
- Polarimetric QPE rate algorithms - 3.5.
- Z_{DR} - 4.5.
- K_{DP} - 4.5.
- ρ_{HV} - 4.0.
- KOUN overall - 4.33.

Respondents were also asked to rate on the same scale the help received from available training materials, case studies, and from NSSL staff on duty:

- Online training - 4.0.
- Online case studies - 4.25.
- NSSL staff - 4.67.

The responses received strongly suggest the KOUN polarimetric WSR-88D and its products, including base products, the hydrometeor classification algorithm, and the QPE algorithms, were quite useful to forecasters in making short term forecasts and warning decisions. "The program was a wonderful success", wrote one forecaster, who used KOUN data extensively.

In some cases, respondents said the QPE products were used in the decision NOT to issue Flash Flood Warnings, in the cases where the traditional R(Z) radar rainfall estimators were too high. This is "one of the best aspects of dual-pol[arization radar]", said one forecaster. In addition, several forecasters stated KOUN products help them better define the exact locations and areal extent of the hail threat. This "increased confidence in warnings", according to one forecaster.

The base data also helped forecasters identify thunderstorm updrafts, increasing their understanding of storm morphology in real time. One forecaster said, "...the ability to identify these updrafts AND their location relative to the echo core explicitly, was very important in short term forecasting of storm evolution."

6. Summary

The Joint Polarization Experiment (JPOLE) was designed to test the engineering design and determine the data quality of the polarimetric KOUN WSR-88D radar, demonstrate the utility and feasibility of the radar to operational users, and to collect data and information that could be used to perform a cost/benefit analysis.   JPOLE data collection was conducted in three phases. During the first phase, from March 15, 2002 through June 15, 2002, efforts primarily focused on addressing calibration issues, improving the delivery system, and resolving an interference problem with a nearby radar.   During the second phase, from June 15, 2002 through March 15, 2003, KOUN data were intermittently collected and delivered to operational forecasters at the Norman, OK NWS office on a case by case basis. Work also continued to improve data quality, enhance algorithm performance, and streamline the real-time data processing and delivery system. Finally, during the third phase, from March 15, 2003 through June 15, 2003, a concerted effort was made to collect a comprehensive dataset (including ground-based verification data) for all weather events. A KOUN scanning strategy was designed to, as much as possible, emulate the

elevation angles, scanning rates, and volume coverage times of the standard WSR-88D VCP 11. Furthermore, to obtain more feedback from forecasters, NSSL observers were scheduled to assist NWS forecasters in the analysis and interpretation of the polarimetric radar data and products for each event that occurred during this "intense" 3 month data collection period. In several instances, KOUN data and products proved to provide value-added information to the warning decision process. Results of the operational use of the polarimetric data and products, as well as a summary of the forecaster evaluations and comments, are presented within this report.

In total, KOUN data were collected for 98 events during the entirety of the JPOLE data collection period. A summary of these data is described online at http://cimms.ou.edu/~heinsel/jpole/database.html (events listed chronologically) and http://cimms.ou.edu/~heinsel/jpole/stormtype.html (events listed by storm type). Overall, the KOUN radar was found to routinely produce polarimetric measurements of exceptional quality. An engineering evaluation of the calibration and performance of the KOUN radar, which further discusses data quality during the early stages of JPOLE data collection, is presented by Melnikov et al. 2003.

Analysis of the JPOLE data has also been a crucial element of the JPOLE effort. Complementary reports by Ryzhkov et al. (2003) and Schuur et al. (2003a) demonstrate the polarimetric KOUN radar's ability to improve rainfall estimation and hydrometeor classification capabilities, respectively. Since KOUN is a proof-of-concept polarimetric WSR-88D radar, and the first in a possible future national network of polarimetric WSR-88D radars, improvements in data quality, rainfall estimation, and hydrometeor identification have far reaching implications. These economic benefits from such improvements are summarized in a decision briefing to the NEXRAD Program Management Committee on polarimetric WSR-88D radar.

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Appendix A

VCP TABLES

Table 1: HYBRID VCP

Task Name: **HYBRID_A, HYBRID_B**
Name of Product Scheduler: **HYBRID**
RRDA VCP Name: **HR-45**
Time of execution: **6 min 37 sec**

Task Name	# of Elevations	Elevations (degrees)	PRF (Hz)	Unamb. range (km)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA Az. resolution (degrees)
HYBRID_A	15	0.0	446	300	12	48	0	0.5
HYBRID_B		0.5	446	300	12	48	0	0.5
		1.5	446	300	12	48	0	0.5
		2.5	1013	148	27.8	48	0	0.5
		3.5	1013	148	27.8	48	0	0.5
		4.5	1013	148	27.8	48	0	0.5
		5.5	1013	148	27.8	48	0	0.5
		6.5	1013	148	27.8	48	0	0.5
		7.5	1013	148	27.8	48	0	0.5
		8.7	1013	148	27.8	48	0	0.5
		10.0	1013	148	27.8	48	0	0.5
		12.0	1013	148	27.8	48	0	0.5
		14.0	1013	148	27.8	48	0	0.5
		16.7	1013	148	27.8	48	0	0.5
		19.5	1013	148	27.8	48	0	0.5

Table 2: CONVECTIVE VCP

Task Name: **CONVECTIVE**
Name of Product Scheduler: **CONVECTIVE**
RRDA VCP Name: **HR-46**
Time of execution: **5 min 24 sec**

Task Name	# of Elevations	Elevations (degrees)	PRF (Hz)	Unamb. range (km)	Unamb. velocity (m/s)	# of samples	Doppler filter, (m/s)	RDDA Az. resolution (degrees)
CONVECTIVE	15	0.0	1013	148	27.8	48	0	0.5
		0.5	1013	148	27.8	48	0	0.5
		1.5	1013	148	27.8	48	0	0.5
		2.5	1013	148	27.8	48	0	0.5
		3.5	1013	148	27.8	48	0	0.5
		4.5	1013	148	27.8	48	0	0.5
		5.5	1013	148	27.8	48	0	0.5
		6.5	1013	148	27.8	48	0	0.5
		7.5	1013	148	27.8	48	0	0.5
		8.7	1013	148	27.8	48	0	0.5
		10.0	1013	148	27.8	48	0	0.5
		12.0	1013	148	27.8	48	0	0.5
		14.0	1013	148	27.8	48	0	0.5
		16.7	1013	148	27.8	48	0	0.5
		19.5	1013	148	27.8	48	0	0.5

Table 3: TORNADO VCP

Task Name: **TORNADO**
Name of Product Scheduler: **TORNADO**
RRDA VCP Name: **HR-47**
Time of execution: **1 min 15 sec**

Task Name	# of Elevations	Elevations (degrees)	PRF (Hz)	Unamb. range (km)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA Az. resolution (degrees)
TORNADO	3	0.0	1281	117	35.2	64	±3.0	0.5
		0.5	1281	117	35.2	64	±3.0	0.5
		1.5	1281	117	35.2	64	±3.0	0.5

Table 4: TORNADO_1 VCP

Task Name: **TORNADO_1**
Name of Product Scheduler: **TORNADO**
RRDA VCP Name: **HR-51**
Time of execution: **2 min 05 sec**

Task Name	# of Elevations	Elevations (degrees)	PRF (Hz)	Unamb range (km)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA Az. resolution (degrees)
TORNADO	5	0.0	1281	117	35.2	64	±3.0	0.5
		0.5	1281	117	35.2	64	±3.0	0.5
		1.5	1281	117	35.2	64	±3.0	0.5
		2.5	1281	117	35.2	64	±3.0	0.5
		3.5	1281	117	35.2	64	±3.0	0.5

Table 5: RHI_1 VCP (Z_{DR})

Task Name: **VR-146**
RRDA VCP Name: **VR-146**
RVP-7's elevation resolution: **1^0**
Time of execution: **2 min 40 sec**

Task Name	# of RHI cuts	Elevations (degrees)	PRF (Hz)	Unamb. range (km)	Azimuthal step (degrees)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA El. resolution (degrees)
VR-146	11	0.0 to 50	1013	148	1	27.8	64	0	0.5

Table 6: RHI_2 VCP (Z_{DR})

Task Name: **VR-146**
RRDA VCP Name: **VR-147**
RVP-7's elevation resolution: **0.5^0**
Time of execution: **4 min 09 sec**

Task Name	# of RHI cuts	Elevations (degrees)	PRF (Hz)	Unamb. range (km)	Azimuthal step (degrees)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA El. resolution (degrees)
VR-146	11	0.0 to 50	1013	148	1	27.8	64	0	0.5

Table 7: RHI_3 VCP (Z_{DR})

Task Name: **VR-146**
RRDA VCP Name: **VR-149**
RVP-7's elevation resolution: **0.5^0**
Time of execution: **1 min 45 sec**

Task Name	# of RHI cuts	Elevations (degrees)	PRF (Hz)	Unamb. range (km)	Azimuthal step (degrees)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA El. resolution (degrees)
VR-146	7	0.0 to 30	1013	148	1	27.8	64	0	0.5

Table 8: RHI_4 VCP (LDR)

Task Name: **LDR_VR-146**
RRDA VCP Name: **VR-146**
RVP-7's elevation resolution: 1^0
Time of execution: **2 min 40 sec**

Task Name	# of RHI cuts	Elevations (degrees)	PRF (Hz)	Unam. range (km)	Azimuthal step (degrees)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA El. resolution (degrees)
LDR_VR-146	11	0.0 to 50	1013	148	1	27.8	64	0	0.5

Table 9: RHI_5 VCP (LDR)

Task Name: **LDR_VR-146**
RRDA VCP Name: **VR-147**
RVP-7's elevation resolution: 0.5^0
Time of execution: **4 min 09 sec**

Task Name	# of RHI cuts	Elevations (degrees)	PRF (Hz)	Unam. range (km)	Azimuthal step (degrees)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA El. resolution (degrees)
LDR_VR-146	11	0.0 to 50	1013	148	1	27.8	64	0	0.5

Table 10: RHI_6 VCP (LDR)

Task Name: **LDR_VR-146**
RRDA VCP Name: **VR-149**
RVP-7's elevation resolution: 0.5^0
Time of execution: **1 min 45 sec**

Task Name	# of RHI cuts	Elevations (degrees)	PRF (Hz)	Unam. range (km)	Azimuthal step (degrees)	Unamb. velocity (m/s)	# of samples	Doppler filter (m/s)	RDDA El. resolution (degrees)
LDR_VR-146	7	0.0 to 30	1013	148	1	27.8	64	0	0.5

(a) KOUN Database of 2002 and 2003 Events by Type	
Tornadic	
Date	**Description**
May 8-9, 2003	Tornadic Supercell w/ little hail
May 9-10, 2003	Tornadic Supercell w/ copious hail
May 16, 2003	Tornadic Storm with Supercellular Characteristics
Hail	
April 12, 2002	Convective cells w/ heavy rain and hail
June 4, 2002	Mature Squall Line w/ Hail and Heavy Rain
June 12, 2002	Convective Cells w/ Hail Signatures in Woods and Kay Co.
June 16, 2002	Mature Squall Line w/ Hail
March 13, 2003	Intensifying Squall line w/ hail
April 23, 2003	Convective Cells w/ hail
April 24, 2003	Supercell that evolves into bow-shaped echo
April 29, 2003	Convective cells w/ hail in far southwestern OK
May 1, 2003	Convective cells w/ hail, followed by Biological Scatterers and AP around KOUN
May 4, 2003	Biological Scatterers in Clear Air, followed by Convective Cells w/ Hail Signatures
May 6, 2003	Convective Cells w/ Hail Signatures
May 8-9, 2003	Tornadic Supercell w/ Few Hail Signatures
May 9-10, 2003	Tornadic Supercell w/ Many Hail Signatures
May 10, 2003	Convective Line with Hail Signatures
May 14, 2003	Several Convective Cells w/ Large Hail
May 20, 2003	Line of Convective Cells w/ hail
June 10-11, 2003	Squall Line w/ Hail, Heavy Rain, and AP Behind Line
June 11-12, 2003	Low Precipitation Storms w/ Hail

Table 11. KOUN database of 2002 and 2003 events by type: (a) tornadic and hail, (b) mesoscale convective systems, (c) convective and warm-season stratiform, (d) cold-season stratiform, mixed precipitation, and snow, and (e) non-meteorological scatterers in clear air.

(b) KOUN Database of 2002 and 2003 Events by Type	
Mesoscale Convective System	
May 26, 2002	Convective and Stratiform Precipitation with a Bright Band
June 4, 2002	Mature Squall Line w/ Hail and Heavy Rain
June 5, 2002	Mature Squall with Heavy Rain Decays as it moves Across Eastern Oklahoma
June 16, 2002	Mature Squall Line w/ Hail
September 13, 2002	Stratiform with convective line
October 28, 2002	Asymmetric Squall Line
March 13, 2003	Intensifying Squall line w/ hail
April 19, 2003	Morning squall line with afternoon convective cells and dry line
May 20, 2003	Line of Convective Cells w/ hail
May 23, 2003	Stratiform Precipitation w/ Embedded Convective Cells
June 5, 2003	MCS over Southern Oklahoma
June 25-26, 2003	Two squall lines
Mesoscale Convective System with AP and/or Biological Scatterers	
May 27, 2002	"Splitting" Convective Line w/ AP behind
June 9, 2002	Convective Cells, Stratiform Precipitation, and Biological Scatterers
June 13, 2002	Two Squall Lines with AP (some embedded) and Biological Scatterers
August 13, 2002	Multiple Squall Lines, Gust Fronts, AP, and Biological Scatterers
August 14, 2002	Convective and Stratiform Precipitation and Biological Scatterers around KOUN
August 24, 2002	Convective cells, Gust Fronts, AP, and Insects
September 14, 2002	Multiple convective lines w/ Copious Biological Scatterers
September 18-19, 2002	Convective Line ahead of a Cold Front with flying biological scatterers
October 03, 2002	Flying Creatures ahead of Squall Line
October 29, 2002	End of 28 October 2002 squall line, with AP and Biological Scatterers
May 16, 2003	Nighttime MCS with Biological Scatterers
May 24, 2003	Multiple Squall Lines with AP and Biological Scatterers
May 25, 2003	MCS Along Red River with AP and Biological Scatterers
June 4, 2003	MCS with Biological Scatterers
June 6, 2003	Squall Line with Biological Scatterers Ahead/Behind Line
June 10-11, 2003	Squall Line w/ Hail, Heavy Rain, and AP Behind Line
June 11-12, 2003	MCS with AP Behind
June 14, 2003	MCS with AP

(c) KOUN Database of 2002 and 2003 Events by Type	
Convective	
May 17, 2002	Line of Convective Cells associated with Cold Front, and Flying Creatures
May 25, 2003	Precipitation bands associated with a Cold Front, and AP NW of KOUN
May 28, 2003	Rain bands Around Upper-Level Low
June 8, 2002	Convective Cells and Biological Scatterers
August 12, 2002	Weak line of cells with Biological Scatterers SE of KOUN
September 15, 2002	End of 14 Sept event w/ Copious Biological Scatterers
October 06, 2002	Convective Cells embedded w/in KOUN clutter
October 20, 2002	Weak Cells embedded in AP
March 4, 2003	Strong Cold Front w/ weak convective cells
May 17, 2003	Few weak convective cells around KOUN
June 1, 2003	Convective Cells East of KOUN
Warm Season Stratiform	
April 7, 2002	Stratiform Precipitation
April 13, 2002	Stratiform precipitation w/ a few convective cells in south-central OK
May 12, 2002	Frontal Passage with light precipitation
June 18, 2002	Moderate Stratiform Precipitation with Bright Band
August 27, 2002	AP behind and embedded w/in stratiform precipitation
September 8, 2002	Stratiform Precipitation
September 9, 2002	Stratiform Precipitation
April 28, 2003	Stratiform Precipitation
May 15, 2003	Stratiform Precipitation in Northern Oklahoma
May 21, 2003	Stratiform Precipitation in Southern Oklahoma

(d) KOUN Database of 2002 and 2003 Events by Type	
Cold-season Stratiform	
October 01, 2002	Light Stratiform Precipitation
October 08, 2002	State-wide Stratiform Precipitation
October 09, 2002	Light Stratiform Precipitation
October 18, 2002	Moderate Stratiform Precipitation with Bright Band
October 23, 2002	Moderate Stratiform Precipitation with Bright Band
November 1, 2002	Light Stratiform Rain over southern Oklahoma
November 2, 2002	Light Stratiform Rain over Oklahoma
November 4, 2002	Light Stratiform Rain over Oklahoma
February 18, 2003	Light Stratiform Precipitation
February 20-22, 2003	Light Stratiform Precipitation
Cold-season Stratiform with AP and/or Biological Scatterers	
October 19, 2002	Two Moderate Stratiform Precipitation Systems, A Bright Band, and Biological Scatterers
October 24, 2002	Moderate Stratiform Precipitation with a bright band, Chaff , AP, and Biological Scatterers
October 25, 2002	End of 24 Oct '02 Stratiform Precipitation with AP and Biological Scatterers
October 27, 2002	Stratiform Precipitation, AP, and Biological Scatterers
November 5, 2002	End of 4 November Stratiform Rain, AP, and Biological Scatterers
December 9, 2002	Light Stratiform Precipitation w/ embedded non-meteorological scatterers
December 10 2002	End of 9 Dec '02 Light Stratiform Precipitation w/ non-meteorological scatterers
Mixed-Phase Precipitation	
December 3-4, 2002	Winter Storm with Snow, Freezing Rain, and Rain
February 26-27, 2003	Freezing drizzle / Light snow
Snow	
January 12, 2003	Snow bands
January 16, 2003	Cold front with light snow
February 6, 2003	Snow bands in central OK with Chaff Signature
February 23, 2003	Heavy snow (20" in Ponca City!)
February 24-25, 2003	Red River Snow

(e) KOUN Database of 2002 and 2003 Events by Type	
Non-meteorological Scatters in Clear Air	
May 16, 2002	Biological Scatterers around KOUN in Clear Air
August 28, 2002	Significant Anomalous Propagation around KOUN
August 29, 2002	Significant Anomalous Propagation around KOUN
January 18, 2003	Example of Interference NW of KOUN
February 06, 2003	Snow bands in central OK with Chaff Signature
May 1, 2003	Convective cells w/ hail, followed by Biological Scatterers around KOUN and AP
May 4, 2003	Biological Scatterers in Clear Air, followed by Convective Cells w/ Hail Signatures
May 5, 2003	Biological Scatterers Around KOUN
May 8-9, 2003	Tornadic Supercell w/ little hail and Biological Scatterers Afterward
May 18, 2003	Biological Scatterers Around KOUN
May 19, 2003	Biological Scatterers and AP w/ Convective Line over far NW OK
May 22, 2003	Biological Scatterers Around KOUN
June 13, 2003	AP Around KOUN, Followed by Convective Cell Development over OK
June 15, 2003	Convective Cell Development over central OK, Followed by AP and Biological Scatterers around KOUN
July 15, 2003	Insects Along Convergence Boundaries

Appendix C

Post-shift questionnaire

Date: *Summary of responses*   Place a "➤"or "x" next to your response except where noted.

1. During this event, I consulted the hydrometeor classification algorithm (HCA):
                    __ Continuously   _**3** Frequently   _**2** A few times   _**1** Not at all
                    (if "not at all", please explain in comments section and skip to question 7.)
    2. The HCA discrimination of hail was:
                    _**2** Excellent   _**3** Good   __ Poor   __ Very poor _**1** Did not use
    3. The HCA discrimination of "big drops" was:
                    _**1** Excellent   _**1** Good   __ Poor   __ Very poor _**4** Did not use
    4. The HCA discrimination of non-precipitating scatterers (e.g., insects, AP) was:
                    __ Excellent   __ Good   __ Poor   __ Very poor _**6** Did not use
    5. Was the HCA directly used in the decision-making process for any warnings/advisories?
                    _**3** Yes   _**3** No   *(if "yes", please explain in the comments section*
    below.)
    6. The HCA was a positive contribution to the warning process:
              _**3** Strongly agree _**2** Agree   __ Neutral   __ Disagree   __ Strongly disagree

7. During this event, I consulted the Quantitative Precipitation Estimation Algorithms (QPEAs):
                    __ Continuously   __ Frequently   _**4** A few times   _**3** Not at all
                    (if "not at all", please explain in comments section and skip to question 13.)
    8. For all QPEAs used during this event, please rate the algorithm's performance (Excellent, good, poor, or very poor) in the appropriate grid box.

	Z	**Z-Z$_{DR}$**	**Z$_{DR}$-K$_{DP}$**	**K$_{DP}$**
1 hr accumulation	Poor-1			Good-1
3 hr accumulation	Poor-1			Good-1
Storm total	Poor-2			Excellent-1
1 hour rate	Poor-1			

    9. The QPE **rate** algorithms correctly outlined regions of very heavy rain:
                    _**2** Agree   __ Disagree   _**4** Did not use
    10. Were QPEAs directly used in the warning decision-making process?
                    _**3** Yes   _**3** No   *(if "yes", please explain in the comments section*
    below.)
    11. The polarimetric QPE **accumulation** algorithms were a positive contribution to the
       warning process (leave blank if accumulation algorithms were not used):
                    __ Strongly agree _**4** Agree   __ Neutral   __ Disagree   __ Strongly disagree
    12.The polarimetric QPE **rate** algorithms were a positive contribution to the warning process
       (leave blank if rate algorithms were not used):
                    __ Strongly agree _**1** Agree   __ Neutral   __ Disagree   __ Strongly disagree

13. During this event, I consulted the polarimetric base products: _**7** Yes   __ No
                    (if "no", please explain in comments section and skip to question 26.)
    14. Please check all base polarimetric products that were used: _**7** Z$_{DR}$ _**2** K$_{DP}$ _**2** ρ$_{HV}$
    15. Z$_{DR}$ was useful in detecting hail:

_7 Agree   __ Disagree   __ Did not use or not applicable

16. Z_{DR} was useful in detecting regions of very heavy rain:
_5 Agree   __ Disagree   _2 Did not use or not applicable

17. Z_{DR} was useful in detecting regions of large drops above the melting level (i.e., updrafts):
_4 Agree   __ Disagree   _3 Did not use or not applicable

(over, please)

18. Z_{DR} was useful in detecting the melting level (e.g., melting snow/graupel):
__ Agree   __ Disagree   _7 Did not use or not applicable

19. Z_{DR} was useful in detecting tornado debris:
__ Agree   __ Disagree   _7 Did not use or not applicable

20. Z_{DR} was useful in detecting non-precipitating scatterers (e.g., AP, insects):
__ Agree   __ Disagree   _6 Did not use or not applicable

21. K_{DP} was useful in detecting regions of very heavy rain:
_3 Agree   __ Disagree   _4 Did not use or not applicable

22. ρ_{HV} was useful in detecting regions of mixed phase precipitation (e.g., melting layer, rain/hail mixtures):   _2 Agree   __ Disagree   _5 Did not use or not applicable

23. ρ_{HV} was useful in detecting regions of very large hail:
_1 Agree   __ Disagree   _6 Did not use or not applicable

24. ρ_{HV} was useful in detecting tornado debris:
__ Agree   __ Disagree   _7 Did not use or not applicable

25. The base polarimetric products were a positive contribution to the warning process:
_2 Strongly agree   _5 Agree   __ Neutral   __ Disagree   __ Strongly disagree

26. Overall, the KOUN polarimetric WSR-88D added value to issued warnings and advisories:
_3 Strongly agree   _4 Agree   __ Neutral   __ Disagree   __ Strongly disagree

Please offer any comments, including those about WDSS-II, here (use extra sheets, if necessary):

- QPEAs supported decisions to <u>not warn</u> for flash floods.

- Used Z_{DR} to discriminate hail cores – increased confidence in warnings

- Used (HCA) to determine a more precise location and areal extent of hail

- KDP-based precip estimates were better than Z-R when compared to Mesonet. Our confidence in KDP allowed us to place less emphasis and time on investigating large Z-R estimates provided by the traditional 88D rainfall algorithms. Many problems with W23 process during zoom and recenters. Process would hang requiring a "kill" command from command line.

- Dual-pole base data was very useful in identifying new vigorous updrafts. $Z_{DR}/K_{DP}/\rho_{HV}$ also very useful in complement to KTLX data to pinpoint largest hail. In addition to being useful simply for the identification of new/vigorous updrafts – the ability to identify these updrafts <u>AND</u> their location relative to the echo core explicitly, was very important in short term forecasting of storm evolution. Even 2 hours after initiation, new updrafts remained anchored on the extreme west or southwest of the new reflectivity cores – suggesting that forcing for new updraft development remained tied directly to the dryline circulation – instead of discreet intense updrafts propagating away from the dryline into the warm sector. This helped us gain confidence in a much lower risk of discreet supercells/tornadoes than was perhaps expected before initiation.

Appendix D

End-of-project Questionnaire

Name: *Summary of responses*   (*optional, for follow-up questions and clarification)*

Instructions: Please provide a rating on a scale of 0-5 (unless otherwise noted) in the blank next to the question. "5" is the "best", and "0" is the "worst", and half points are allowed. "N/A" should be used when you cannot assign a rating ("not applicable"). Please add comments in the space provided. Use the back of the sheets if you need more room for comments.

I. Questions about the Hydrometeor Classification Algorithm (HCA) *(0-worst to 5-best)*

1. Rate the HCA's ability to depict the location of hail: **4.1** - *5 responses*
   - My confidence in the HCA is high – at least from the cases I worked. Still limited by radar horizon problem at medium/far ranges for near-surface hydrometeor type sampling.
   - During the times I used the data, we did not receive reports of hail in areas where the HCA indicated no hail; Conversely, hail reports and HCA 'hail positives' seemed to coincide reasonably well.

2. Rate the HCA's ability to depict the location of "big drops", particularly those in updrafts above the freezing level: **4** - *4 responses*

3. Rate the HCA's ability to classify non-precipitating scatterers (e.g., AP, insects, chaff): **4.25** - *2 responses*

4. Did the HCA classifications exhibit realistic vertical continuity? **4** – *4 responses plus 1 "yes"*

5. Did the HCA classifications exhibit realistic time continuity? **4.25** – *4 responses plus 1 "yes"*

6. Did the HCA add value as a nowcasting/warning tool? **3.875** – *4 responses plus 1 "yes"*

II. Questions about the Quantitative Precipitation Estimation Algorithms (QPEAs)

(0-worst to 5-best)

7. Rate the performance of the traditional "Z" algorithms: **2.75** – *6 responses*
   - Subject to severe over-estimation when hail/far ranges involved. Occasionally did a good job for storms at closer ranges late in severe season (i.e., June).

8. Rate the performance of the "Z-Z_{DR}" algorithms: **3.25** – *4 responses*

9. Rate the performance of the "Z_{DR}-K_{DP}" algorithms: **4.1** – *5 responses*

10. Rate the performance of the "K_{DP}" algorithms: **4.2** – *5 responses*

11. Did the QPE **accumulation** algorithms add value as a flood forecasting/warning tool? **4.8**
    - 5 responses plus 1 "yes"
    - Very useful in several events where traditional algorithms over-estimated amounts.
    - I felt the polarimetric QPE algorithms based on Z_{DR}-K_{DP} and K_{DP} were superior in every way to the traditional WSR-88D. This includes spatial resolution, gradients, and accuracy.
    - One of the "best" aspects of dual pol.
    - In a couple of events, the precipitation estimates appeared much better than traditional Storm Total Precipitation which frequently seemed to overestimate.

12. Did the QPE **rate** algorithms add value as a flood forecasting/warning tool? **3.5**
    - 2 responses plus 1 "yes"
    - Didn't use this, but seeing as how the accumulation algorithms did well, seems that rate algorithms derived from Z_{DR}/K_{DP} would perform well and could be very valuable over sensitive basins/urban areas.
    - See second comment in # 11.
    - It could.

13. Was the performance of each QPE accumulation algorithm consistent for all time length intervals (i.e., 1 hr, 3 hr, and storm total)? **4** – *2 responses plus 1 "yes"*
    - Did not look at this enough to have an opinion.

III. Questions about the base polarimetric products *(0-worst to 5-best)*

14. Was Z_{DR} useful in the detection of hail? **4.3** - *5 responses*
    - Most effective when used along with ρ_{HV}/K_{DP}/environmental data.
    - Few opportunities for me.

15. Was Z_{DR} useful in the detection of large drops above the freezing level (i.e., updrafts)? **4.17**
    - 3 responses
    - Especially useful on May 10 (already documented in post-shift survey).

16. Was Z_{DR} useful in the detection of the precipitation melting level? **4** – *1 response*

17. Was Z_{DR} useful in the detection of tornado debris? **2.5** – *2 responses*
    - Although there is no doubt this is a use of Z_{DR} – Z_{DR} did not tell us anything we didn't already know from the debris ball from TDWR/KTLX.

18. Was Z_{DR} useful in the detection of non-precipitating scatterers? **4.17** – *3 responses*

19. Was Z_{DR} a useful nowcast/warning tool? **4.5** – *4 responses*

20. Was K_{DP} useful in the detection of regions of very heavy rain? **4.375** – *4 responses*

21. Was K_{DP} a useful nowcast/warning tool? **4.5** - *4 responses*

22. Was ρ_{HV} useful in the detection of regions of mixed phase precipitation? **4**
    - 2 responses plus 1 "yes"

23. Was ρ_{HV} useful in the detection of regions of very large hail? **4** – *2 responses plus 1 "yes"*

24. Was ρ_{HV} useful in the detection of tornado debris? **2.5** – *2 responses*
    - See note from question 17.

25. Was ρ_{HV} a useful nowcast/warning tool? **4** – *3 responses*
    - Should be noted that $Z_{DR}/K_{DP}/\rho_{HV}$/HCA are very powerful tools when used <u>together</u> – none are a stand-alone solution.

IV. Miscellaneous questions   *(0-worst to 5-best)*

26. Overall, did the provided polarimetric data and algorithms add value to the nowcasting and warning decision-making processes? **4.33** – *6 responses*

27. Was the online training material sufficient to understand the HCA? **4** – *2 responses*
   - Wasn't aware of it
   - Didn't look too much at the on line stuff – simply didn't have time with everything going on this spring. What Kevin showed me was very good.
   - Did not view online info, only the "user information" notebook.

28. Was the online training material sufficient to understand the QPEAs? **4** – *1 response*
   - Wasn't aware of it
   - Didn't look too much at the on line stuff – simply didn't have time with everything going on this spring. What Kevin showed me was very good.
   - I do not believe I fully understand the difference in all the QPEs and is the reason I left this question blank.

29. Was the online training material sufficient to understand Z_{DR}? **4** – *2 responses*
   - Wasn't aware of it
   - Didn't look too much at the on line stuff – simply didn't have time with everything going on this spring. What Kevin showed me was very good.

30. Was the online training material sufficient to understand K_{DP}? **4** – *2 responses*
   - Wasn't aware of it
   - Didn't look too much at the on line stuff – simply didn't have time with everything going on this spring. What Kevin showed me was very good.

31. Was the online training material sufficient to understand ρ_{HV}? **4** – *2 responses*
   - Wasn't aware of it
   - Didn't look too much at the on line stuff – simply didn't have time with everything going on this spring. What Kevin showed me was very good.

32. Were the online case studies helpful? **4.25** – *2 responses*

33. Were the NSSL meteorologists able to sufficiently answer questions and provide assistance as necessary? **4.67** – *6 responses*
   - Good to have you guys/gals over here.
   - Efforts of Kevin Scharfenberg/Pam Heinselman/Don Burgess/Arthur Witt and Terry Schuur are to be highly commended.
   - Most were happy to answer questions and help with interpretation.

Overall comments

- Overall, I think the program was a wonderful success. It was exciting to integrate new concepts and more science into forecasting on a daily basis. As you probably noticed, only a few people from the OUN office took a great interest in the program, despite the relevance of the material. I'm still in school, so I took to the program rather well compared to some others, but I still found the polarimetric concepts intimidating. It took quite a while before I reached a comfort zone, and even now I still do not completely understand the differences in the QPE algorithms. The ability to expand this program NWS-wide may depend on how successfully the material and new concepts can be taught to NWS meteorologists, both young and old. A part of the difficulty had to do with WDSS-II, which I sent comments about in a separate e-mail. Thanks for everything.

- I did not have the opportunity to look at the data as much as I would have liked to.