

HIGHLIGHTS FROM THE JOINT POLARIZATION EXPERIMENT OPERATIONAL DEMONSTRATION

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1. INTRODUCTION

In 2002, the National Severe Storms Laboratory's research WSR-88D (KOUN) was upgraded to include polarimetric capabilities. Data from KOUN were delivered in real time to the National Weather Service's Norman, Oklahoma Weather Forecast Office (WFO) for evaluation. As part of the Joint Polarization Experiment (JPOLE), KOUN polarimetric data and algorithms were used at the WFO during the decision-making and forecasting processes for severe convection, flash floods, and winter storms. During the first phase of JPOLE (May 2002 through early March 2003), data were available to forecasters on an event-driven basis, subject to radar availability. Data were more frequently delivered during the Intense Observation Period (IOP), extending from 15 March through 15 June 2003.

Investigators of research polarimetric radar (PR) have stated that this technology allows accurate depiction of hydrometeor characteristics, as well as greatly reduced errors in radar rainfall estimation (e.g., Zrnić and Ryzhkov 1999). To test the operational utility of this technology, WFO forecasters used and evaluated KOUN polarimetric "base" products and their derivatives, including differential reflectivity (Z_{DR}), cross-correlation coefficient (ρ_{HV}), and specific differential phase shift (K_{DP}). Details about these products are available in Doviak and Zrnić (1993). In addition, a polarimetric hydrometeor classification algorithm (HCA; Schuur et al. 2003a) and experimental polarimetric quantitative precipitation estimation algorithms (QPEAs; Ryzhkov et al. 2003) were also examined. Forecasters were asked to fill out evaluation forms at the end of their shift and at the end of the season. The results of these evaluations and more information about JPOLE are provided in Schuur et al. (2003b and 2004).

2. WINTER WEATHER FORECASTING

Data from KOUN Polarimetric WSR-88D were made available to WFO forecasters on an event-driven basis during the winter of 2002 - 2003. A brief summary of results from two winter storms are presented here.

2.1 *The 3-4 December 2002 winter storm*

On 3-4 December 2002, a winter storm moved across Oklahoma, with a variety of precipitation types ranging from snow in northwest Oklahoma, to freezing rain and ice pellets in parts of central Oklahoma, to rain in the southeast part of the state. KOUN data were used in real time to evaluate the slope and evolution of the snow melting layer over central Oklahoma (Scharfenberg and Maxwell 2003).

The HCA-detected boundary between snow and rain was closer to the radar in the northwestern quadrant, and farthest from the radar to the southeast. This output indicated the melting level was sloped upward toward the southeast, as was confirmed with the available synoptic data. HCA output from KOUN also enabled forecasters to observe the melting level slowly descend with time during the evolution of the event as the cold air deepened from northwest to southeast. This was especially important during the time between scheduled upper air soundings because it enabled forecasters to "see" the decreasing melting level, and evaluate the performance of short-range model guidance in accurately predicting the critical low-level thermodynamic profile. Indeed, the boundaries separating snow and ice, and separating ice from rain, moved slowly southeastward as the storm progressed. In mountainous regions, a similar use of the HCA may be to identify the altitude of the snow level, aiding governments, road crews, and local tour and ski industries.

2.2 *The 24 February 2003 heavy snow event*

On 24 February 2003, a winter storm produced up to ten inches of snow across southern Oklahoma. The initial forecast for the affected area called for primarily ice pellets, mixed with some freezing rain, then changing to snow before ending. Although forecasters acknowledged that if a means to sufficiently cool the warm layer aloft could be realized, there was a chance that the precipitation type could change to all snow, resulting in heavier accumulation than initially forecast. With the primary precipitation type expected to be ice pellets, overall accumulations were forecast to be limited to three inches or less in southern Oklahoma. Although ice pellets were mixed with snow early in the event, the precipitation changed to all snow within about two hours after the onset of precipitation as enhanced upward motion from intense frontogenesis and embedded convection, along with a contribution

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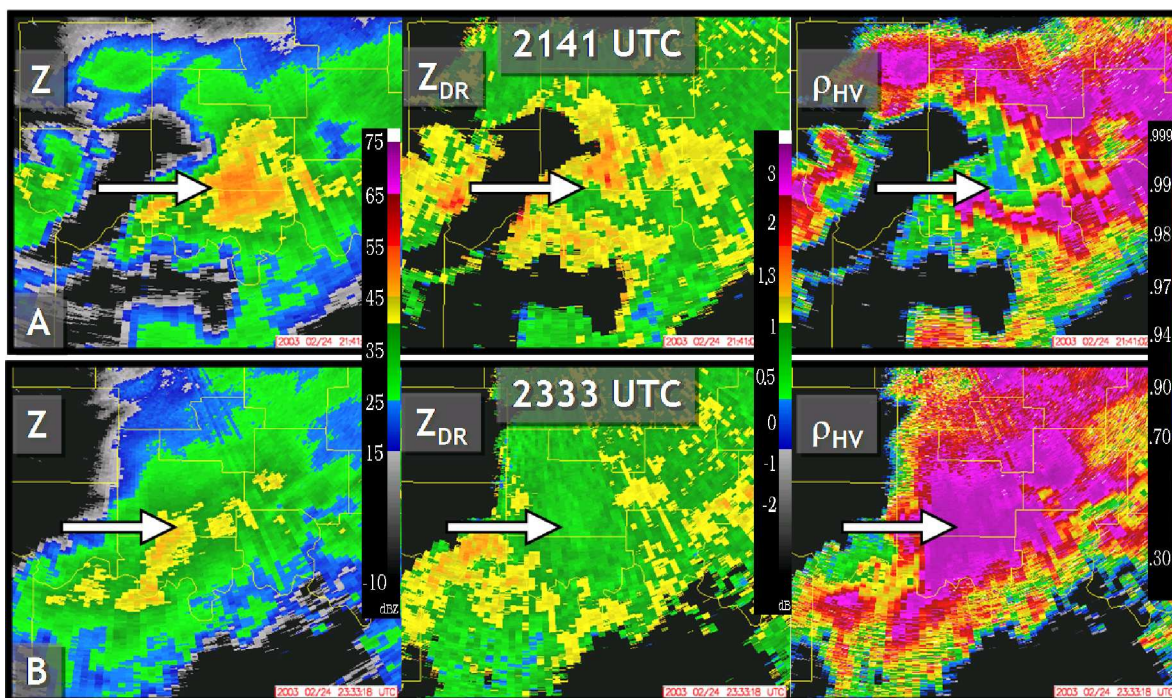


Figure 1. KOUN polarimetric WSR-88D reflectivity (Z), differential reflectivity (Z_{DR}) and cross-correlation coefficient (ρ_{HV}) during winter storm of 24 February 2003. **a)** Early in event, high Z , high Z_{DR} and low ρ_{HV} (arrows) suggested precipitation was mixed in phase. **b)** Later, lower Z_{DR} and high ρ_{HV} suggest precipitation had changed to a single type.

from latent cooling due to snow melt within the elevated warm layer, cooled the atmospheric column sufficiently to support all snow.

KOUN data were critical in alerting forecasters to the rapid evolution of precipitation types (Miller and Scharfenberg 2003). Initially, during the mixed-phase precipitation, KOUN images (Figure 1a) showed large areas of high Z_{DR} (around 1.5 dB) and low ρ_{HV} (0.95 or less) in the heavy precipitation area (high reflectivity in Figure 1a). These signatures are consistent with a mixture of precipitation types. Later (Figure 1b), although the precipitation had changed to all snow, conventional reflectivity images showed little change over time. However, Z_{DR} values had become more uniform near 0.5 dB, while ρ_{HV} values had increased substantially to above 0.99. Such a change in polarimetric variables indicated a transition from mixed-phased precipitation to a more uniform precipitation type. This data evolution prompted forecasters to call spotters, who confirmed the precipitation had changed from a mixture of snow and ice pellets to only snow, with heavy snowfall rates observed in some locations. The storm produced widespread reports of six inches or more of snow, greater than the average snowfall totals for the entire winter in some areas. In this case, PR data was critically important in two ways: 1) it allowed forecasters to observe the rapid change in predominant precipitation type, and thus 2) played a very important role in enhancing forecaster situation

awareness that the previously acknowledged possibility of cooling the warm layer aloft was in fact being realized. This significantly increased forecaster confidence and resulted in a Winter Weather Advisory being upgraded to a Heavy Snow Warning, likely with several hours additional lead time than would have been realized without the availability of KOUN data.

3. RAINFALL ESTIMATION AND FLASH FLOOD FORECASTING

One of the most promising aspects of PR is the improvement of radar rainfall estimates. WFO forecasters were provided with several experimental polarimetric QPEAs during the JPOLE IOP. Forecasters noted on several occasions that rainfall estimates from KOUN increased confidence in **not** issuing Flash Flood Warnings.

A heavy rain event occurred on 19 October 2002 between 100 and 200 km southeast of KOUN. The "traditional" $R(Z)$ algorithm, similar to those run on the WSR-88D network nationally, showed a band of rain totals in excess of six inches (Figure 2a). An algorithm using K_{DP} data from KOUN (Figure 2b) showed much lower estimated totals. Rain reports from the Oklahoma Mesonet, superimposed on the images in Figure 2, show the lower totals from KOUN were much more reasonable. The traditional $R(Z)$ algorithm suffered from contamination due to the "bright band"

echo of melting snow aloft in this case. Forecasters said KOUN data increased their confidence there was little flash flood threat. Note also in Figure 2 the polarimetric QPEA suffers less from partial beam blockage than the traditional R(Z) algorithm (Zrnić and Ryzhkov 1996).

Improvements to traditional algorithms are greatest in cases of reflectivity contamination from hail, the bright band, AP, ground clutter, and other non-meteorological scatterers (Zrnić and Ryzhkov 1996). After the JPOLE IOP, the various polarimetric QPEAs were combined into a single "synthetic" polarimetric QPEA, which takes advantage of each polarimetric variable's strongest characteristics (e.g., greater use of K_{DP} in very heavy rain). A quantitative analysis of the improved results of the synthetic algorithm is available from Ryzhkov et al. (2003) and Schuur et al. (2004).

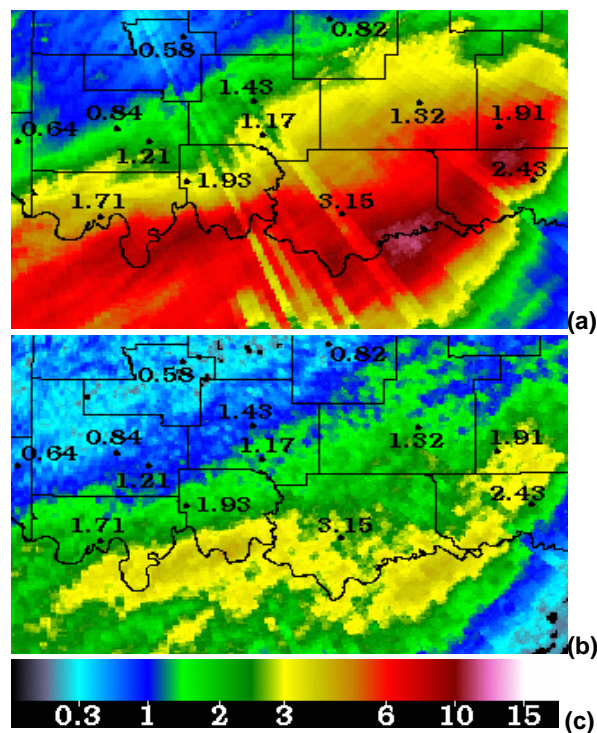


Figure 2. Oklahoma Mesonet precipitation totals from 19 October 2002 (inches). **a)** Traditional R(Z) rainfall estimate. **b)** Polarimetric K_{DP} algorithm estimate. **c)** Key to color rainfall estimates (inches).

4. DEEP, MOIST CONVECTION AND ASSOCIATED HAZARDS

The area covered by the National Weather Service WFO at Norman, Oklahoma frequently experiences severe thunderstorms. During the JPOLE IOP in spring 2003, numerous severe thunderstorms were observed, many of which produced large hail and tornadoes. This allowed forecasters numerous opportunities to use and evaluate KOUN PR data during severe thunderstorms.

4.1 Hail detection

Over 650 hail reports occurred within 200 km of KOUN PR during the JPOLE IOP (Figure 3). In most of these cases, PR data and HCA were used in real time hail forecasting at the WFO. Two hail "chase" vehicles were also deployed in several cases during the JPOLE IOP. These vehicles provided high-density observations of hail, so that the HCA's ability to discriminate hail could be quantified. In a head-to-head comparison with the operational WSR-88D hail detection algorithm (Witt et al. 1998) on five storm days, the HCA at the lowest KOUN elevation angle provided a slightly higher probability of detection and much lower probability of false detection (Table 1).

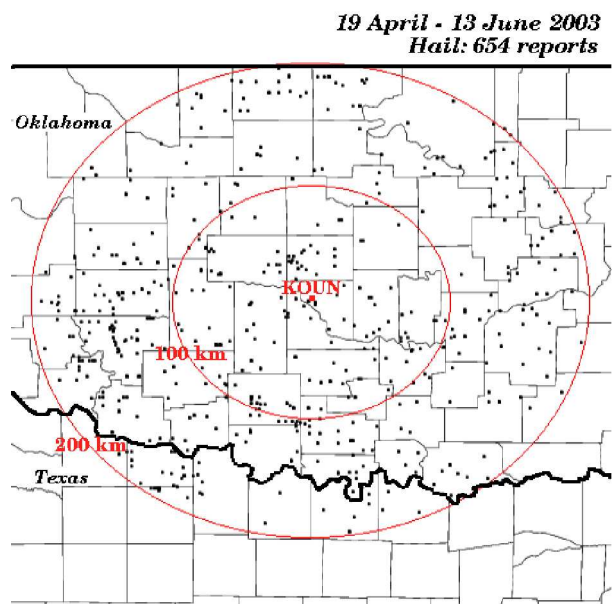


Figure 3. Hail reports (all sizes) within 200 km of the KOUN polarimetric WSR-88D during the JPOLE IOP.

Table 1. Probability of detection (POD), probability of false detection (POFD), and critical success index (CSI) for the operational WSR-88D Hail Detection Algorithm (HDA, from KTLX WSR-88D) and the polarimetric Hydrometeor Classification Algorithm (HCA, from KOUN polarimetric WSR-88D) on five storm days during the Joint Polarization Experiment.

	POD	POFD	CSI
WSR-88D HDA	.88	.39	.56
Polarimetric HCA	.94	.08	.86

Hail is typified in PR data by a region of enhanced reflectivity (Figure 4a), co-located with low Z_{DR} (Figure 4b), and low ρ_{HV} (Figure 4c). HCA's hail discrimination allows forecasters and users to determine exactly where in the storm hail is located, to the nearest radar gate. In contrast, the operational

WSR-88D hail detection algorithm only gives a probability of the presence hail anywhere in an entire detected "storm cell".

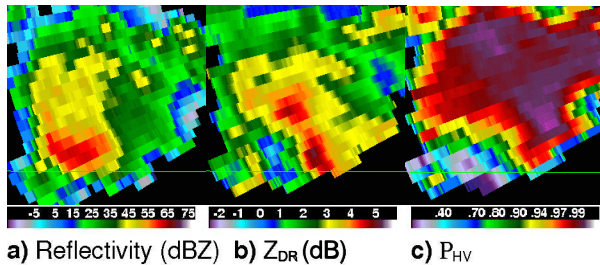


Figure 4. Typical large hail signature on PR. Coincident with high reflectivity (a), is a "hole" of low differential reflectivity (b), and a region of low cross-correlation coefficient (c).

4.2 Tornado debris detection

During the JPOLE IOP, debris from strong tornadoes was identified at short ranges by PR. High reflectivity, low Z_{DR} and very low ρ_{HV} were observed at the tip of hook echoes while significant amounts of structural debris were being lofted. Schuur et al. (2003a and 2004) show an example of this signature. Although this signature does not provide any lead time, it provides high confidence that damage is occurring, which enables forecasters to confidently issue precise, location-specific follow-up statements that a damaging tornado is in progress, thus enhancing communication with spotters, emergency managers, and the media. The debris detection signature could also be exceptionally valuable in the detection of tornadoes at night and in sparsely-populated areas, when ground-truth confirmation from spotters is often lacking. It should be noted, however, that the ability to detect the debris signature is highly range-dependent, and as is the case with traditional Doppler radar data, the ability of the radar to detect lofted debris may be limited at distant radar range.

4.3 Operational use of the " Z_{DR} column" signature

PR users have often noted a "column" of enhanced Z_{DR} associated with the updraft of thunderstorms (Conway and Zrnić 1993). This column apparently represents the detection of liquid hydrometeors rising in the updraft above the surrounding freezing level. During JPOLE, the Z_{DR} column was found to often be coincident with a bounded weak echo region (BWER) and/or low ρ_{HV} values in supercell storms.

The case of 10 May 2003 is an excellent example of the operational utility of the " Z_{DR} column" signature. Central Oklahoma had been affected by tornadic supercell thunderstorms on the previous two days, with an F4 tornado affecting southern sections of Oklahoma City on 8 May, and an F3 tornado affecting

the northeast part of the Oklahoma City metro area on 9 May. Atmospheric conditions were once again highly favorable for the development of severe thunderstorms along a dryline in central Oklahoma on 10 May. Evaluation of wind shear and deep layer flow vectors suggested conditions were highly favorable for the development and sustenance of potentially tornadic supercell thunderstorms, much like the previous two days. Based on these forecast data, the Storm Prediction Center and the Hazardous Weather Outlook issued by WFO Norman indicated a "high risk" of severe thunderstorms to the east of the dryline, and a "particularly dangerous situation" Tornado Watch was issued before the storms initiated. The threshold for forecasters at WFO Norman to issue a radar-based Tornado Warning on this day was also lower than usual due to the perceived enhanced threat.

Although thunderstorms did develop, forecasters using KOUN data noted Z_{DR} columns associated with strong convective updrafts remained anchored to the "fine line" echo of the dryline. Moreover, as storms propagated eastward away from the dryline, Z_{DR} columns weakened significantly. This strongly suggested the updrafts were being forced by the dryline circulation, and for whatever reason, vigorous updrafts were unable to be maintained in the warm sector. Thus, forecasters at WFO Norman very quickly deduced something was "wrong" with the environment, and that the risk for tornadic supercells in areas east of the dryline was much lower than initially expected. This enhancement of forecaster situation awareness resulted in an abrupt change in philosophy of how the event was handled, which is one of the most difficult things to accomplish in mid-event within a WFO forecast team. The overall message theme in forecast products, graphical guidance, warnings, and statements from WFO Norman was quickly changed to one more representative of a typical severe weather day. This was particularly important after two days of high-end severe weather within the same areas.

4.4 Other potential uses

Various studies have suggested that precipitation particle distribution and cloud microphysics near the up-shear flank of supercells might be important to tornadogenesis or tornadogenesis failure (Markowski 2002). As more data are gathered on supercell thunderstorms, differences in microphysics between storms may be revealed in PR data, perhaps leading to a much higher degree of confidence in radar-based tornado warnings, and a reduction in false alarms.

In addition, study is ongoing that suggests the phase change from hail to rain in downdraft columns of microburst-producing thunderstorms is at times directly observable with a PR (Scharfenberg 2003). The diabatic cooling associated with such a phase change is often a major contributor to microburst strength.

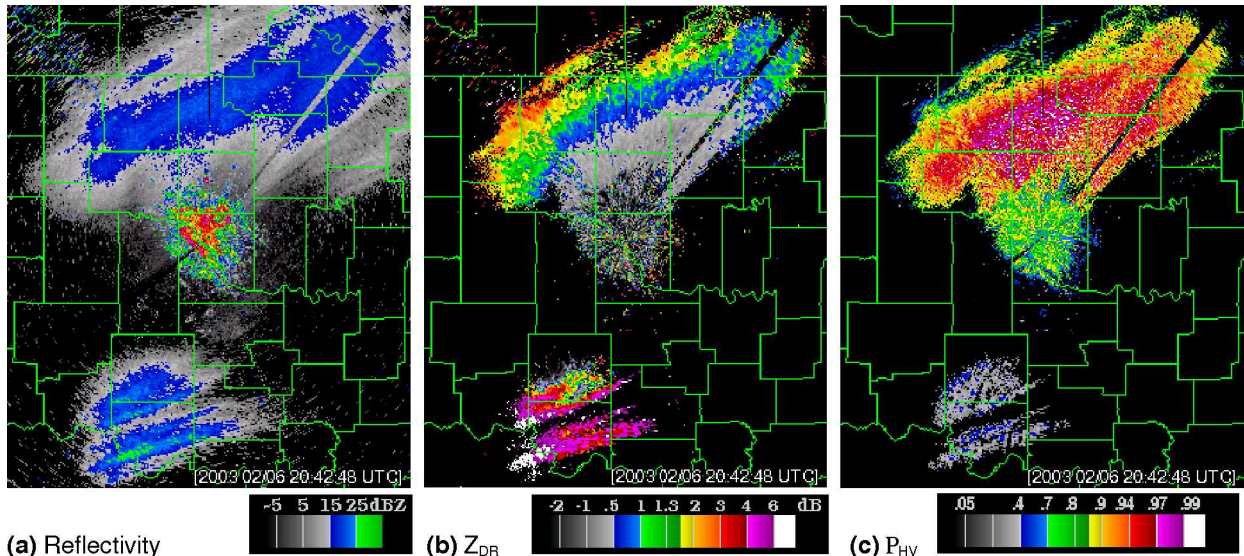


Figure 5. Chaff is observed south and southwest of KOUN polarimetric WSR-88D on 6 February 2003.

5. OTHER OPERATIONAL APPLICATIONS

Among other operational uses, the HCA may be used to discriminate non-meteorological echoes from meteorological echoes. Current research suggests birds may be discriminated from passive wind tracers, potentially aiding in the reduction of bird contamination from VAD wind profiles. The HCA also opens the possibility of better ground clutter and AP canceling, and may also allow other users, such as air traffic controllers, to remove all non-precipitating echoes from their displays.

The ability to discriminate non-meteorological scatterers is well-illustrated by the case of 6 February 2003. On that date, a band of snow was moving across northern Oklahoma. A region of echoes that had similar conventional reflectivity characteristics appeared in southwestern Oklahoma (Figure 5a), but the high Z_{DR} (Figure 5b) and very low ρ_{HV} (Figure 5c) revealed these echoes were not meteorological in nature. These echoes were apparently the result of chaff released upstream.

6. FUTURE CHALLENGES AND OPPORTUNITIES

Several improvements to the HCA have been undertaken since the JPOLE IOP and are ongoing. In particular, discrimination between light rain and light snow remains difficult, as their polarimetric characteristics heavily overlap. “Low-precipitation” supercells have polarimetric characteristics similar to weak tropical thunderstorms, making hail discrimination difficult.

After the JPOLE IOP, the various polarimetric QPEAs were combined into a single “synthetic” polarimetric QPEA (Ryzhkov et al. 2003), which takes advantage of each polarimetric variable’s strongest

characteristics (e.g., greater use of K_{DP} in very heavy rain). The “synthetic” algorithm may need operational testing in a number of environments for fine-tuning.

Research is ongoing relating storm electrification to PR characteristics. PR data are needed for study in several areas, particularly regarding detection and prediction of microbursts, the microphysics associated with tornadogenesis, supercooled liquid drops hazardous to aircraft, and changes of precipitation type and evolution in strong winter storms.

7. CONCLUSIONS

Polarimetric WSR-88D data were delivered to WFO Norman, Oklahoma for real time use and evaluation for more than a year. These data were well-received by forecasters, and made numerous contributions to the forecast decision-making process during winter storms, potential flash flooding, and severe thunderstorms.

Rainfall accumulation estimates from the polarimetric QPEAs were superior to the traditional R(Z) estimators in most cases, particularly during bright banding, heavy rain, and hail events. The HCA allowed forecasters to better understand the location and evolution of hydrometeors during severe thunderstorms, as well as the evolution of the melting level during winter storms. Forecasters, the algorithms they use, and users will also benefit from the HCA’s ability to discriminate non-meteorological echoes.

Overall, WFO forecasters stated the polarimetric WSR-88D products aided their decision-making process. Lead time and accuracy increased in some cases, while false alarms, particularly for hail and flash flooding, decreased. Situation awareness and forecast confidence were both enhanced.

8. ACKNOWLEDGEMENTS

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