J3.15

RAINFALL ESTIMATION AND HYDROMETEOR TYPE CLASSIFICATION WITH A POLARIMETRIC WSR-88D RADAR

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1. INTRODUCTION

The accurate estimation of precipitation type and accumulation has been a long-standing problem for operational meteorologists and hydrologists. When the estimates are obtained by weather radar, inaccuracies can result from radar miscalibration, attenuation of the signal in heavy precipitation, and the presence of non-meteorological scatterers such as ground returns, birds, and insects. Natural variations in the size, shape, and ice density of cloud and precipitation particles can also result in estimation uncertainties. Fortunately, many of these problems may be at least partially mitigated through the use of radar polarimetry.

As part of the evolution and future enhancement of the WSR-88D, the National Severe Storms Laboratory (NSSL) recently upgraded the KOUN WSR-88D radar to include polarimetric capabilities. Since this radar is the first in a possible future national network of polarimetric WSR-88D radars, it represents a significant advance in our ability to improve rainfall estimation and hydrometeor type classification on a large scale. In this paper, we describe polarimetric rainfall estimation and hydrometeor type classification techniques, provide examples of polarimetric products, present initial impressions of the utility of the polarimetric upgrade to the WSR-88D radar, and discuss future plans for the operational demonstration of the KOUN radar's capabilities.

2. RADAR POLARIMETRY

Weather radar polarimetry has been discussed previously by Zrnic (1996) and Zrnic and Ryzhkov (1999). In this paper, we discuss data collection by the polarimetric KOUN WSR-88D radar (Fig. 1). Unlike most conventional weather radars, which transmit only horizontal (microwave frequency) electromagnetic waves, polarimetric radars transmit and receive energy at both horizontal and vertical polarizations. By then comparing the power and phase shifts of the horizontal and vertical returns, additional information is obtained on the microphysical structure of the cloud and precipitation.

In the Spring of 2002, several years of effort on the NOAA research WSR-88D radar culminated in the generation and display of dual polarization radar data and products. As part of the Joint Polarization

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Figure 1: The polarimetric KOUN WSR-88D radar.

Experiment (JPOLE, discussed later in this paper) operational demonstration, these data and products were delivered in real-time to operational forecasters at the Norman, OK National Weather Service (NWS) forecast office. Data and products delivered include radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), differential phase (Φ_{DP}), specific differential phase (K_{DP}), a hydrometeor classification product, and a variety of polarimetric rainfall rate and accumulation estimates. More information on polarimetric radars and their use to identify precipitation types can be found at www.nssl.noaa.gov/dualpol.

3. POLARIMETRIC PRODUCTS

There are two fundamental hydrological and meteorological benefits of polarimetric radar: rainfall estimation and hydrometeor classification. In this section, we present examples of polarimetric rainfall estimation and hydrometeor classification using data collected by the KOUN radar for a Mesoscale Precipitation System (MCS) that passed through central Oklahoma on 16 June 2002.

3.1 Rainfall Estimation

Historically, Z-R power law relationships have been used to provide radar-based rainfall accumulation estimates. Rainfall estimation based on reflectivity alone is, however, subject to a variety of inaccuracies.

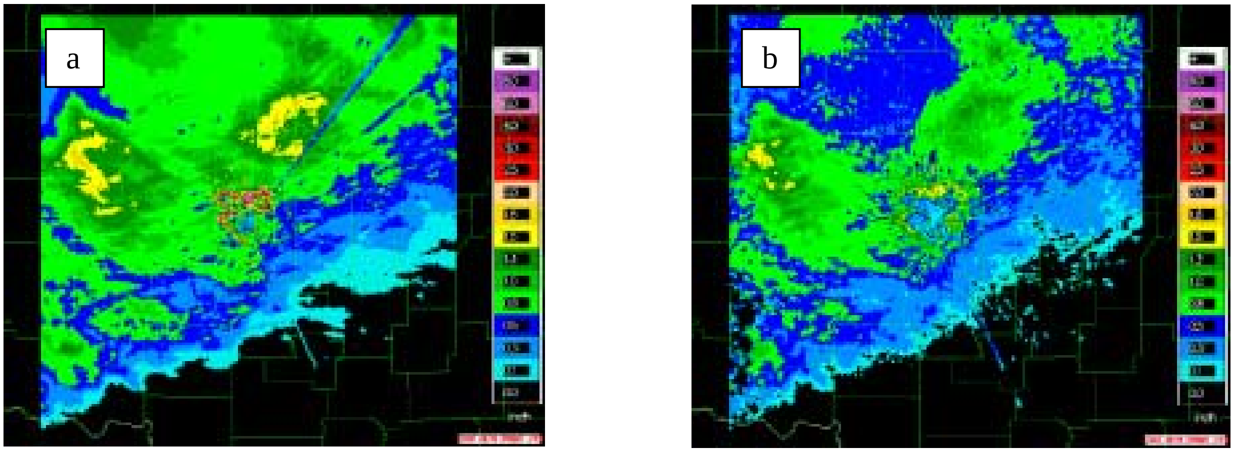

Figure 2: KOUN WSR-88D 3-hour rainfall accumulation using a) a Z-R relation, b) polarimetric K_{DP} relation.

For example, natural variations in drop size distributions have been shown to result in rainfall overestimation by as much as a factor of ten (Schuur et al., 2001). Measurements can be further compromised by attenuation, blockage, and radar calibration errors. Fortunately, many of these problems may be at least partially mitigated by using polarimetric rainfall estimation techniques.

Some of the benefits of polarimetric rainfall estimation are demonstrated by Fig.2, which shows a comparison of 3-hour rainfall accumulation using the conventional NWS R(Z) power law relation ($Z = 300R^{1.4}$) and the polarimetric $R(K_{DP})$ power law relation ($R = 40.6K_{DP}^{0.866}$). In addition to demonstrating better overall agreement with ground-based rainfall observations (obtained from the Oklahoma mesonet, not shown), the polarimetric K_{DP} estimation technique clearly shows the relative immunity of the polarimetric estimator to blockage (see the sector of severe blockage at an azimuth of approximately 40° in Fig. 2a). In this case, the blockage is caused by the NWS KCRI test and development radar, which is located approximately 250 m to the NW of the KOUN radar. Blockage represents a significant rainfall estimation problem for several regions of the country, particularly in the mountainous western states. Advantages of rainfall estimation techniques that use combinations of polarimetric variables, such as $R(K_{DP}, Z_{DR})$ or $R(Z, Z_{DR})$, are discussed by Brandes et al. (2001) and Ryzhkov et al. (2002).

3.2 Hydrometeor Classification

A second benefit of polarimetric weather radar is its ability to classify and quantify hydrometeor types. Several hydrometeor classification techniques have been described in the literature. Like other algorithms (e.g., Vivekanandan et al, 1999; Straka et al. 2000), the NSSL polarimetric Hydrometeor Classification Algorithm (HCA) uses "fuzzy logic" to weight Z, Z_{DR}, K_{DP}, and ρ_{HV} to determine the most likely hydrometeor type for each region of the cloud. The resulting product, which was delivered to operational forecasters in the Spring of 2002, includes categories for light rain (LR), moderate rain (MR), heavy rain (HR), hail (Ha), and big drops (BD). Non-meteorological categories, such as anomalous propagation (AP), and birds and insects (BI), are also identified by the algorithm. Separate categories for dry snow, wet snow, and cloud ice are included in a winter precipitation HCA being developed for the Fall of 2002.

Results of the HCA for an intense hail core that occurred along the convective line of the 16 June 2002 MCS are shown in Fig. 3. At times, Zs associated with this hail core reached 69 dBZ. The most notable polarimetric features associated with this intense hail core, as identified by the HCA, are a significant local minimum in the Z_{DR} and a significant drop in ρ_{HV} (not shown). A more comprehensive description of hydrometeor identification in this system is presented by Schuur et al. (2003). Preliminary results suggest that polarimetric methods of identifying precipitation type far exceed those from routines that use only conventional radar data.

4. JPOLE - OPERATIONAL DEMONSTRATION

In addition to addressing engineering and data quality issues, the JPOLE Operational Demonstration will provide an opportunity to demonstrate the operational benefits of weather radar polarimetry to operational hydrologists, meteorologists, and aviation users. This will be accomplished by conducting an evaluation of the performance of polarimetric radar rainfall and hydrometeor products in both 1) real-time with the collaboration of operational forecasters, and 2) post-analysis where a more detail analysis of polarimetric algorithm performance can be made.

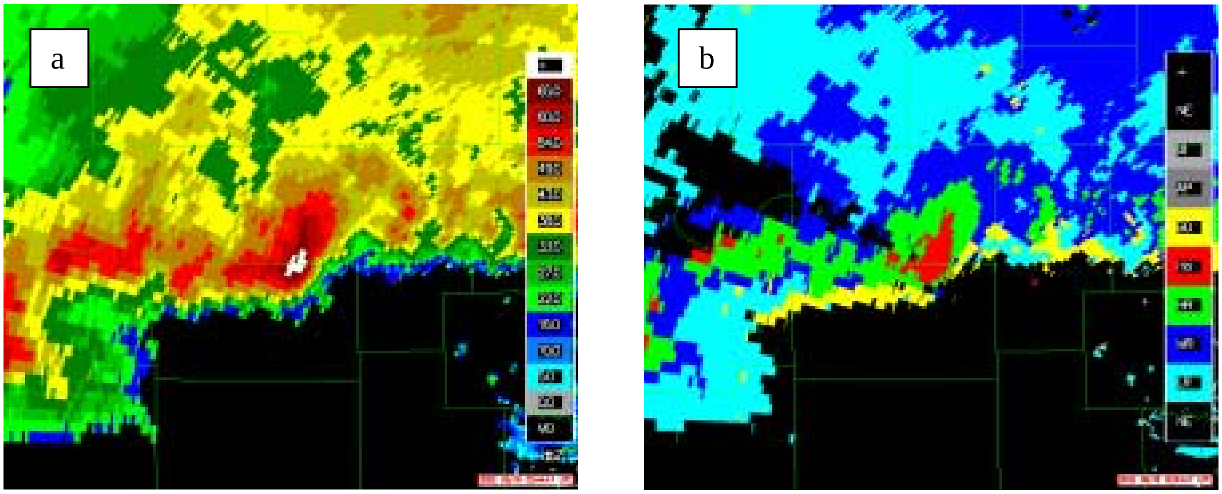

Figure 3: KOUN WSR-88D a) reflectivity, and b) polarimetric hydrometeor classification for the June 16, 2002 MCS at 0045 UTC. The meteorological categories include 1) light rain (LR), 2) moderate rain (MR), 3) heavy rain (HR), 4) hail (Ha), and 5) big drops (BD). The non-meteorological categories include 1) anomalous propagation (AP), and 2) birds and insects (BI).

More specifically, the product performance evaluation objectives are to

- Improve Quantitative Precipitation Estimation (QPE)
- Use QPE to 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
- Provide improved initial conditions and constraints to numerical models for short term forecasts
- Investigate the feasibility of identifying aircraft icing conditions

Product comparisons will be of fundamental importance to the test and evaluation of the polarimetric KOUN WSR-88D radar's capabilities. As such, it is imperative that real-time data collection be conducted in collaboration with operational hydrologists, meteorologists, and aviation users, whose insight will be of vital importance to the evaluation of WSR-88D radar products.

A more comprehensive overview of the JPOLE operational demonstration can be found on the JPOLE web site, located at: http://www.nssl.noaa.gov/JPOLE/.

5. SUMMARY

Several data sets have now been collected with the polarimetric KOUN WSR-88D radar. A preliminary evaluation indicates that polarimetric rainfall estimation and hydrometeor classification algorithms outperform conventional algorithms. Work will continue to improve existing hydrometeor classification and rainfall estimation techniques, develop algorithms for winter precipitation, and facilitate the transfer of polarimetric radar technology to operational meteorologists, hydrologists, and aviation users.

Given the long-term prospect of a future network of polarimetric WSR-88D radars, JPOLE has the potential to have a far-reaching impact for operational meteorologists, hydrologists, and aviation users at a national scale.

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