

# NOAA/NSSL's WSR-88D Radar for Research and Enhancement of Operations:

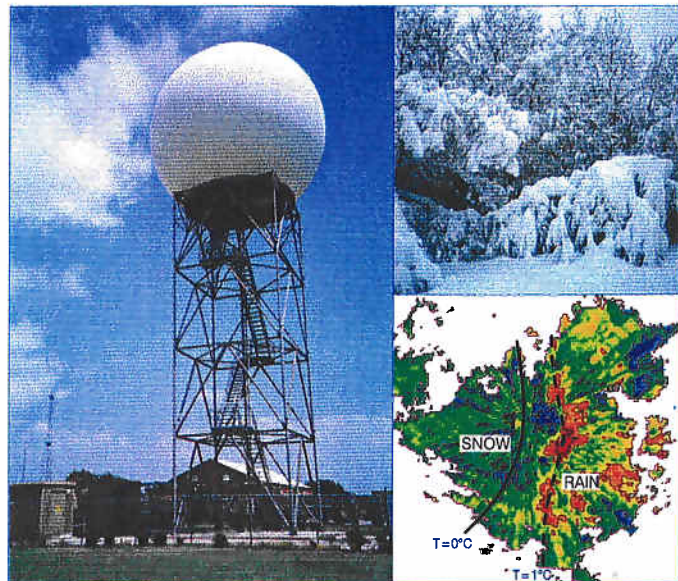
## Polarimetric Upgrades to Improve Rainfall Measurements

### National Severe Storms Laboratory Report

*prepared by:* R. J. Doviak and D. S. Zrnić

*with contributions from:* J. Carter, A. Ryzhkov, S. Torres, and A. Zahrai

**April 1998**



National Oceanic and Atmospheric Administration  
**National Severe Storms Laboratory**  
Norman, Oklahoma 73069

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RESEARCH and ENHANCEMENT OF OPERATIONS:

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TO IMPROVE RAINFALL MEASUREMENTS**

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## PREFACE

The National Severe Storms Laboratory (NSSL) is the leading NOAA agency for advancing weather radar research, engineering, and applications. Prominent among the high impact projects and experiments conducted at the NSSL was the Joint Doppler Operational Project (JDOP) which gave impetus to the design and establishment of the NEXRAD (now the WSR-88D). To a large part, the WSR-88D is based on the experience with the research Doppler radars developed by NSSL staff. The media for informing the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service (NWS) management and staff about hardware advances in radar techniques are NSSL reports specifically tailored to the weather agencies' needs. Following extensive research in the mid eighties, two reports dealing with dual polarization capabilities for the NEXRAD were generated for the NWS. (These report titles are listed on the last page of this report.) Since then, more research has been done, and new experiences have emerged. In this spirit, the present report is a successor to those previous reports. It is meant to document the details that lead us to favor a novel scheme for obtaining polarimetric variables in order to improve the quantitative estimation of precipitation. Furthermore, it describes hardware changes in the microwave and antenna assemblies, as well as measurements of the antenna patterns before and after the modifications to the research WSR-88D (designated KOUN1). The report is written for engineers and managers, and the information it contains is detailed enough to gauge the basis upon which recommendations are made for upgrades to the network of WSR-88Ds. This report describes the effects that changes in antenna hardware for polarimetric upgrades have on the radiation patterns, and provides information necessary for making decisions on the selection of a polarization basis. Possible configurations of hardware are also suggested. Ultimately, it is the cost effectiveness (not addressed in this report) that should prevail in the decision process.

## EXECUTIVE SUMMARY

This report focuses on the steps undertaken by the National Severe Storms Laboratory (NSSL) to improve rainfall measurements by adding a polarimetric capability to the research WSR-88D (designated as KOUN1). One of the most important elements in obtaining a good polarimetric radar is a good antenna with low sidelobes and matched radiation patterns (i.e., the distribution of radiated power density vs. angular displacement from the beam axis) for horizontally and vertically polarized waves. The polarimetric characteristics and radiation patterns of the KOUN1 radar are presented in Section II. An engineering evaluation was made to determine if the existing antenna assembly with minimum modification could be used for the dual polarization mode. This is indeed the case; therefore, obvious savings in hardware and manpower would ensue by adopting the proposed design.

Because no pattern measurements were ever made of any WSR-88D antennas on site, it was imperative to make measurements on the KOUN1 antenna before the feed was changed from one which transmits only horizontally polarized waves to one (a dual port feed) which transmits both horizontally and vertically polarized waves. The patterns, before change of feed, demonstrate that there are no significant changes in the quality of the antenna installed in 1988.

A dual port antenna feed was purchased from Andrew Canada, Inc. (manufacturers of the WSR-88D antennas) and installed on the radar. Pattern measurements were made for the horizontal and vertical polarizations. It is comforting to note that the radiation patterns with the dual port feed are very close to those patterns measured with the single port feed. For polarimetric measurements, it is desirable to have a good match of main lobes at horizontal (H) and vertical (V) polarizations. Both copolar patterns have low sidelobe levels and are well matched in the mainlobe. Beamwidths are  $0.93^\circ$  for the horizontal copolar and  $0.90^\circ$  for the vertical copolar patterns. The match of patterns in the lower half of the vertical plane is excellent; it even extends to several of the sidelobes. For the most part, the patterns agree within  $\pm 1$  dB, and the match is best where the gain is largest (i.e., near the beam axis). For the points far removed from the axis, the differences are larger as expected, but because the antenna gain is much smaller in these regions, the differences are much less significant than for those close to the axis.

Cross polarization patterns were also recorded, and it was observed that the WSR-88D specification of  $< -30$  dB is met. The cross-polar pattern at vertical polarization matches in shape the cross-polar pattern at horizontal polarization, but the amplitudes are about 4 dB higher (still within the measurement uncertainty). Consequently, the addition of the dual port feed and the retention of the three struts had not degraded the patterns. Therefore, this configuration is recommended for future polarimetric upgrades of the WSR-88D.

Of critical importance to the favorable utility of a polarimetric radar is the selection of an appropriate polarization basis and its practical implementation. Considerations for the choice of polarimetric basis and a few system design options are described in Section III. The circular and

linear polarimetric bases are compared. It is demonstrated that the circular basis can, in principle, provide estimates of specific differential phase ( $K_{DP}$ ) without switching the transmitted polarization. In weak showers, these estimates are corrupted because the cross-polar signal is almost three orders of magnitude below the copolar signal. But with circular polarization, the cross-polar signal does not depend on the orientation of hydrometeors; furthermore, in combination with the copolar signal, it leads to the measurement of the mean canting angle. Nonetheless, this apparent advantage of the circular polarization basis vanishes in the presence of significant precipitation along the radar beam. A linear polarization basis is well suited for quantitative measurement of rainfall and classification of hydrometeor types without extensive correction of propagation effects. Therefore, our choice rests with the linear H, V basis.

A novel polarimetric scheme employing simultaneous transmission of horizontally and vertically polarized waves is being implemented on the KOUN1 radar. Principally, the motivation for simultaneous transmission is to do away with an expensive high power microwave switch which has been the key component in research polarimetric radars during the 1980s and 1990s. This design includes installation of two receivers that share several common components, but a single receiver can also measure all the polarimetric variables. With two receivers, the dwell time for computing polarimetric variables is reduced, the ground clutter filter is not affected, and maintenance is simpler. On the down side, the depolarization ratio cannot be measured simultaneously with other polarimetric variables, but if desired, it can be measured together with the standard spectral moments in separate volume scans. Having two receivers offers some redundancy that might be advantageous. For comparative testing, NSSL plans to incorporate two receivers in its radar and still provide full WSR-88D compatibility. That is, all current data acquisition modes and scanning strategies can remain as they are, and the impact of polarimetric implementation on the existing algorithms and products should be minimal.

Theoretical evaluation of the effects that feed alignment, drop canting, and backscatter depolarization have on the measurements of polarimetric parameters is made in Section IV for simultaneous transmission and reception of H and V signals. The simultaneous transmission and reception mode is not detrimental to measurements of the specific differential phase and coefficient of correlation between H, V weather echoes. The effects, however, on differential reflectivity of drop canting along propagation paths can be significant. But these effects are harmful only when differential attenuation dominates, which is a problem whether H, V signals are transmitted simultaneously or alternately. Differential reflectivity and the correlation coefficient could be affected by depolarization due to backscattering from hail mixed with rain. On the other hand, backscatter depolarization would accentuate the hail signature of low  $Z_{DR}$  and low  $\rho_{hv}$  (i.e., reduce even more the low values of  $Z_{DR}$  and  $\rho_{hv}$  in hail regions). Thus, the effect might be beneficial.

In summary, the report has demonstrated the following. After the change of feed and one strut on the antenna assembly, the radiation pattern satisfies original WSR-88D specifications. The patterns for horizontal and vertical polarizations are well matched, and the cross-polar pattern is sufficiently suppressed. A linear horizontal and vertical polarization basis is preferred

to a circular basis. The proposed simultaneous transmission and reception of H, V waves is completely compatible with the existing signal processing algorithms on the operational WSR-88Ds. Theoretical analyses of the factors that might affect the precision in measurement of intrinsic polarimetric variables suggests that the simultaneous transmission of H, V waves is a sound method and should be tested.

## ACKNOWLEDGEMENTS

We are grateful to the management and staff of the National Severe Storms Laboratory (NSSL), who provided continued support and encouragement to the Doppler radar project during the formative stages in the development of the National Oceanic and Atmospheric Administration (NOAA)/NSSL's research WSR-88D (i.e., the KOUN1). We thank the National Weather Service (NWS) for providing radar parts that made it possible for the NWS Operational Support Facility (OSF) and NSSL to assemble an updated WSR-88D (i.e., the KCRI) on the campus of the University of Oklahoma's (OU) Research Park. This allowed for the transfer of the prototype WSR-88D (i.e., the KOUN1) to NSSL and provided the OSF with a WSR-88D identical to the operational WSR-88Ds they are responsible to maintain and upgrade. OU's Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) management and staff are thanked for providing personnel to this project. Part of the work described herein was supported by Dr. James Rasmussen, Director of the NOAA's Environmental Research Laboratory, with contributions from his Director's Discretionary Fund.

The staff of the NWS Operational Support Facility (OSF) in Norman, Oklahoma, gave us much needed technical guidance concerning the operation of the KOUN1 and provided critical documentation and materials necessary to implement a polarimetric upgrade which this report addresses. Richard Wahkinney and Mike Schmidt of the NSSL provided crucial technical assistance in the design, fabrication, and installation of the components necessary for the polarimetric upgrades. Dale Sirmans of the Titan Corp. was a source of technical expertise concerning WSR-88D details. Dr. John Fagan of the Electrical Engineering Department of OU supplied the GPS system to determine the locations of test equipment used for antenna pattern measurements on the KOUN1. The Physics Department of OU provided a much needed precision rotator to measure the alignment of the polarization ellipse. Dr. Bringi and Mr. Brunkow of Colorado State University provided the data for Figs. IV.12 and IV.13 from the first experimental comparisons of polarimetric data based on simultaneous and alternate transmissions of H, V polarized waves. Joan O'Bannon drafted several figures and composed the cover.

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