P7R.3 TECHNICAL CONTRIBUTIONS OF MR. DALE SIRMANS TO DOPPLER WEATHER RADAR DEVELOPMENT

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INTRODUCTION

For many in the weather radar community, Dale Sirmans is recognized as the father of the NEXRAD radar. Although Dale did not invent the Doppler weather radar concept, his contribution to the NEXRAD program has earned him this right and title. Through his technical guidance and mild mannered leadership, Dale has helped bring the National Weather Service and the Nation forward from the early 1960s gray scale reflectivity displays to the first modern operational Doppler weather. Starting at the National Severe Storms Laboratory (NSSL) in the 1960s, he made key contributions to the understanding of Doppler weather radar theory, particularly in the field of statistics and moment estimation. He was the lead engineer for the team that built one of the first practical 10 cm radar systems for investigating the use of Doppler measurements for severe weather detection. He made significant contributions to the development of requirements for NEXRAD during the 1970s and for the past 16 years has continued to support the Nation's network of radars by documenting performance, solving unique technical problems, and mentoring a new generation of engineers and scientists who will carry on his work.

Along the way, Dale published several ground-breaking papers and reports, many documenting key milestones in the development of Doppler weather radar. These were always informative, extremely accurate and complete, and remarkably coherent. In addition, Dale contributed to countless other publications, quietly supporting the work of others while always striving to advance the science of weather radar.

This paper discusses some of Dale's significant accomplishments by summarizing many of his technical reports and papers, including works produced at the NSSL, along with many of his more recent achievements while at the Radar Operations Center. The authors intend to leave the reader, both current and future, with the understanding and knowledge of the scope of Mr. Sirmans' contributions to the NEXRAD program through all its phases.

EARLY WORK AT THE SEVERE STORMS LAB

Dale arrived at the embryonic storms laboratory in Norman OK in the early 1960's, first serving as an electronic technician. He initially assisted Roger Lhermitte who had been hired to further the development of weather radar. Brown (2003) and Kessler (1990) describe these early efforts in some detail.

While working for Lhermitte, and with assistance from others, Dale and his team developed a coherent pulse Doppler radar operating with a wavelength of 3 cm. Within a short time after this accomplishment, Lhermitte left the laboratory and Dale was placed in charge of further weather radar development in 1967. Under his guidance, the laboratory obtained and modified a 10 cm radar into a Doppler weather radar system, which became the early model for NEXRAD. By 1971, the lab had a functional 10 cm Doppler radar.

Although Dale certainly played a key role in the hardware development for early Doppler weather development, his most valuable contributions have been in the investigation, analysis, explanation, and fostering of statistical analysis techniques for weather radar moment estimators. He made several significant contributions to the field in the 1970's including identification of the most efficient velocity and spectrum width estimation techniques. One of his earliest reports the authors reviewed concerns the statistics of estimating radar return signal power (Sirmans 1973). This work on radar signal intensity estimation provides one of the best summaries of the theory behind power estimation statistics in the context of weather radar. This NOAA report contains mathematical guidance still useful today when scientists and engineers are designing new radar scan strategies, analyzing receiver components, and evaluating clutter filters.

In one of his most important publications, Dale presented comprehensive results of an investigation into five different techniques of estimating a power spectrum's mean frequency (Sirmans 1975A). This work employed a novel signal simulation technique that is still useful today. A software simulator based on these techniques was recently used to analyze and

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validate a new clutter filter for the WSR-88D (Ice 2004). This simulator is a standard component of the commercial weather radar digital receiver and signal processor system software supplied by Sigmet Inc. which is the basis for the on-going WSR-88D Open RDA upgrade. His frequency estimator analysis work formed the basis for selection and development of the covariance argument or pulse pair processing (PPP) estimation techniques now standard in Doppler weather radars, including NEXRAD. He demonstrated the PPP estimator delivered unbiased estimates for the special case of symmetrical spectral density and white noise, and that it could deliver acceptable bias performance for more general cases. This analysis proved that the PPP estimator was an efficient way to produce velocity estimates, given the signal processing hardware performance constraints of the time. While direct frequency transform methods may someday supplant the PPP estimator, this technique remains the method of choice today. Practical implementation concepts were presented in a paper from around the same time (Sirmans 1975B).

Kessler (1990) also reports that Sirmans played a key role in the implementation of the so called "batch mode" wherein a series of low pulse repetition frequency (PRF) pulses are transmitted, followed by a series of higher PRF pulses, typically within a single azimuthal sample period. This combination of pulses allows for efficient unfolding of range ambiguous echoes without requiring additional elevation scans. The batch mode is in use today with the WSR-88D and was recently implemented by Sigmet Inc. in the commercial signal processor, which is the heart of the WSR-88D Open Radar Data Acquisition (ORDA) upgrade. At the 17th Conference on Radar Meteorology in 1976, NSSL members, including Dale, presented papers on a number of topics related to the range-velocity ambiguity problem. He contributed to the paper by Dr. Richard Doviak, which addressed some early possibilities for mitigating these ambiguities, including the concepts of staggering the PRF and transmitting pulses on two different frequencies (Doviak 1976). This work also contained a comprehensive discussion of limitations imposed by the spectrum width of the signal. In their paper on the use of two sampling rates, Sirmans and Bumgarner describe the dual PRF methods further and present calculations of the expected estimate variances for the velocity products resulting from the techniques (Sirmans 1976). This work included a discussion of confidence measures in the resulting estimates. It is interesting to note how advanced this work was for 1976 when one considers that the NEXRAD program is just now contemplating use of staggered PRT for insertion into WSR-88D scan strategies.

At this same conference, Dale contributed to work analyzing signal propagation attenuation characteristics of 5 cm radars (Weible 1976). At this time, he along with others, was defining the reasons why 10 cm radars should be used for quantitative hydrologic applications. This background would prove useful in his work supporting continued protection of the S-Band frequency allocations for weather radar applications in light of current day efforts to reallocate the band for communications uses.

In 1977 Dale again collaborated with Doviak in producing a comprehensive survey of the problems of range and velocity ambiguities in the context of centimeter Doppler weather radars (Doviak 1978). This paper explains the Doppler dilemma in a particularly lucid fashion, covering the major issues with the design and operation of shorter wavelength radars, focusing on the 10 cm experience at NSSL. The paper is an excellent source on the concept of coherency with regard to the meteorological targets and thoroughly discusses limitations placed on range ambiguity. It further explains early concepts for mitigating range velocity ambiguities, including the use of spaced pairs and dual sampling techniques. At the end of the 1970's, Dale's significant contributions on Doppler radar at the NSSL were described in a wide-ranging tutorial article in the prestigious Proceedings of the IEEE (Doviak, 1979). This article concisely summarized the state of the art at the time, a state greatly advanced in that decade by the efforts of the NSSL team.

TRANSITION TO NEXRAD

By the early 1980's, most of the science and basic engineering principles necessary to develop a usable Doppler weather radar were understood. The 1980's saw a period of requirements definition, validation, and full-scale development of the WSR-88D system. All through this period, Dale played a key role. It is certain he had a major influence in the selection of the critical NEXRAD system level performance requirements, particularly those pertaining to the accuracy of the moment estimators. He was a valuable member of the government and contractor team defining radar hardware specifications, especially those related to critical characteristics such as system phase noise, receiver noise figure, dynamic range and antenna performance. To date, he is sought by program members whenever questions arise or an interpretation of requirements is needed.

During the mid 1980's Dale also investigated issues related to the contamination of meteorological measurements from clutter, studying both normally propagated and anomalously propagated ground target returns. He provided a complete discussion of the characteristics of normal and AP clutter returns, along with explanations of atmospheric propagation models, in a report prepared for the NEXRAD Joint Systems Program Office (Sirmans 1987). This work demonstrated the theory was supported by radar measurements and the proposed NEXRAD clutter filter design was adequate for suppressing clutter contamination due to anomalous propagation conditions. In this work, Dale also discussed differences in signal statistics between normal clutter, AP clutter and precipitation and offered some hope that the inherent signal statistics could be used to automatically recognize AP clutter. It is interesting to note the current WSR-88D system employs an algorithm developed by the National Center for

Atmospheric Research that identifies probable AP clutter using signal statistics.

At the end of the 1980's, the US government had a first production version of the WSR-88D, ready for operational validation. Dale played a significant role in the achievement of this important milestone. Working with members of the NEXRAD program office, representatives from the three major NEXRAD agencies (DOD, DOC, and DOT), and his fellow NSSL scientists and engineers, he supplied major contributions to the NEXRAD Technical Requirements (NTR) document, which formed the basis for the full-scale development of the WSR-88D. The new S-band Doppler weather radar was elegantly described in an invited article for the Microwave Journal, which Dale co-authored with engineers from the NEXRAD prime contractor (Heiss 1990). By early 1990, Dale had left the Storms Laboratory to become the first Chief of the new NEXRAD Operational Support Facility (OSF) Engineering Branch, effectively becoming the Chief Engineer for all WSR-88D operations.

DOCUMENTING NEXRAD PERFORMANCE

The first half of the decade of the 1990's saw the validation, production, and deployment of the WSR-88D network. It was a period of transition from the contractor's development and installation to the government's continued maintenance and support of the network. During 1989-1990, Dale coordinated the initial planning for continued engineering support for NEXRAD and began filling positions in his branch at the OSF—bringing his team of hardware and software engineers together— including authors Ice and Bumgarner. During this period, he was a constant source of technical advice to both the government program office as well as the prime contractor. He continued his research, publishing the first OSF technical report, which discussed one of his frequent topics - issues related to range overlaid echoes (Sirmans 1990). This report presented a quantitative explanation of statistics related to velocity estimation in the particular cases of returns overlaid by second trip echoes. The work included discussions of relative powers of the strong and weak trips and how this relationship affected estimate bias. Some early guidance on how to select adaptable operating parameters for range unfolding algorithms came from this work.

By the end of 1990, however, Dale had retired from government service. Fortunately, after an absence of approximately a year, he returned to the NEXRAD program as an employee of the OSF support contractor, Titan Corporation. Around this time, Dale supported a couple of key technical developments, one concerning the polarization of the transmitted signals. The early design for the WSR-88D was based on transmitting circularly polarized waves. However, this type of signal tends to lose some of its polarization characteristics when propagating through heavy precipitation. The effect on the radar data, particularly reflectivity, is the creation of "shadows" or regions of reduced reflectivity behind area of heavy rainfall. He worked closely with the program office and the prime contractor to validate a proposal to modify the radar to utilize linear horizontal polarization for the transmitted signal.

Upon delivery of the WSR-88D, the prime contractor was required to provide a specified suite of documentation, including technical manuals, drawings, and specifications. This document set was done in accordance with normal government procurement practices and in support of normal maintenance of the baseline. However, the initial documentation requirements did not sufficiently provide for the technical detail behind some of the more complex system design elements. This omission was because the government furnished a number of elements of the system, including specification of moment estimators, clutter filters, and meteorological product algorithms. This level of detail, however, was necessary for the OSF to perform future corrective actions of potential problems and to support development of enhancements. Notable among functions lacking formally documented details were the areas of calibration and clutter filtering. Fortunately for the program, no engineer was more familiar with the intimate details of these critical areas than Dale.

Beginning in mid 1991, OSF engineers requested Dale's help in understanding the WSR-88D design in sufficient detail to foster ease of maintenance and to make it possible to develop enhancements. What followed was a period of prolific report writing. Between September 1992 and March 1993, Dale delivered four major reports documenting the essential elements of the WSR-88D. His report on calibration (Sirmans 1992A) fully described the theory behind the radar's design for initial calibration and for the automatic maintenance of calibration states as the system compensates for hardware changes. This study fully explored the details behind the concept of reflectivity calculation - how the received power is scaled by system parameters to ultimately produce an accurate reflectivity estimate. The report addresses measurement and maintenance of key system component characteristics such as the antenna gain and function, receiver gains and losses, noise handling, and transmitter power. This work formed the basis for several improvements made in the radar calibration procedures used by field technicians.

His report on clutter filtering was exceptionally detailed, fully covering the digital signal processing concepts behind removal of unwanted signal contamination by ground returns (Sirmans 1992B). Dale provided a high level of detail regarding the actual implementation of the 5 pole elliptic filters employed by the WSR-88D, including state diagrams and possible configurations. He described limitations on performance and aspects of practical implementation including a discussion of filter initialization. Included in this comprehensive document are many charts indicating expected biases in the estimates resulting from clutter-filtered data under all operating conditions. Engineers were referring to this report over the past three years as they supported development of the Open RDA signal processor upgrade and evaluation of commercially available clutter filters—again showing the relevancy and value of Dale's documented works.

In a report on volume coverage pattern analysis (Sirmans 1993A), Dale provided a comprehensive tutorial on methods of estimating moment bias and variance statistics as a function of PRF, antenna scan speeds and available sample numbers. This work has been continually useful as the OSF, now the Radar Operations Center (ROC), team members design and evaluate new scanning strategies for the network radars.

In the spring of 1993, Dale finally turned to a strictly hardware project when he delivered a detailed description of the WSR-88D transmitter modulator function. This document, containing detailed diagrams and circuit theory of operation, has become a foundation and roadmap for ROC engineers designing hardware modifications in support of increasing transmitter reliability and reducing long-term costs.

MAINTAINING OUR NATIONAL ASSET

Throughout the 1990's and into the 21st century Dale has been involved in almost every aspect of keeping the national radar network operating effectively. He served on numerous interdisciplinary teams, including groups devoted to improving calibration and increasing the availability of the WSR-88D transmitter. He was frequently called upon to analyze electromagnetic compatibility issues, working to protect the network from unacceptable interference. Working with OSF engineers, Sirmans helped develop a modification to the radar's receiver, reducing its vulnerability to interference from wireless cable television systems that began to appear in the mid 1990's.

In a significant development, he took the lead in solving the challenging technical problems associated with the addition of a new test bed radar system for the Norman OK location of the OSF and NSSL. His analysis of the issues related to operating two WSR-88D radar within 1000 feet of each other resulted in workable solutions regarding tower placement and heights, frequency selection, and added receiver filters. As a result, the OSF/ROC and NSSL teams have had multiple radar systems available for network support and scientific research, often operating 24 hours per day, with no noticeable mutual interference problems.

In 1994, Dale provided a complete analysis of issues related to the coverage of the Los Angeles radar (Sirmans 1994). He described models used to analyze radar coverage as related to measuring key weather parameters and provided some suggested changes in radar operations. In 1997 and 1998, working with OSF engineers and scientists, he determined the probable causes of various anomalies noted in the WSR-88D spectrum width estimates and proposed corrective actions (Sirmans 1998)

He participated in numerous projects that allowed the WSR-88D to continue working well. Every area benefited from his expertise. He provided key inputs to the specification and validation of new power conditioning equipment deployed network-wide. He conducted evaluations of replacement hardware components, including the critical receiver analog to digital converters. By the late 1990's, supplies of a key hybrid circuit component had begun to run out and a major chip manufacturer was contracted to produce a replacement. Because the converter has a major impact on receiver performance and moment estimate accuracy, Dale was called upon to design a test program to validate the new parts. He devised a comprehensive approach, working with members of his team at the OSF and the National Reconditioning Center, to validate the performance of the new devices.

Between 1998 and 2001, ROC engineers investigated upgrading the radar's analog intermediate frequency (IF) receiver components with a modern digital receiver. ROC engineers, with essential help from Dale, were able to identify a commercially available system, the Sigmet RVP7 and integrate it into the NSSL research radar. Subsequent tests, supervised by Dale, resulted in the conclusion that such a system could indeed meet WSR-88D requirements (Sirmans 2000). This work later formed the basis for a decision to employ the Sigmet RVP8 14 bit digital receiver and signal processor as the central element in the Open RDA.

It's difficult to identify an area within the WSR-88D where Dale has not provided some level of engineering support. For example, he played a key role in the identification of new methods for maintaining the radome, providing guidance on cleaning processes as well as a specification for new coatings. He also worked closely with ROC engineers who determined the best methods of employing the solar flux measurements as a means of maintaining system calibration (Sirmans 2001).

Recently, Dale assisted ROC scientists and engineers in identifying a newly discovered problem with elimination of overlaid echoes (Steadham 2004). The so called "Ghost Echo" problem was a latent defect not previously noticed in network operations. The issue came to light with deployment of a new volume coverage pattern. Dale and his team determined the problem was associated with a component of the original hardware signal processor slated for replacement under the Open RDA program. The ROC team was able to provide an interim workaround to the problem pending deployment of the ORDA.

EMBRACING THE FUTURE

The NEXRAD program is on the verge of an exciting new phase. With the impending deployment of the Open RDA, which will provide a new signal processing capability as well as a digital receiver. Engineers and scientists can now seriously consider inserting significant processing enhancements. Dale has been involved in the development and evaluation of many of these improvements in support of the NEXRAD Product Improvement Program. Throughout the development of the Open RDA program, he has continuously supported the engineering team. He assisted with investigations into the use of commercially available time domain clutter filters, which were part of the ORDA solution, identifying areas where the filters did not meet requirements and offering suggestions for mitigating problems. He was a key member of a ROC team that evaluated the contractor's solution, a new spectrally based filter (Ice 2004, 2005). He guided the team in designing simulations and identified important data cases, He assisted with all critical analysis tasks. His background in the development of the original NEXRAD Technical Requirements was crucial to the success of these studies. His participation in ORDA data quality assessment and his identification of possible corrective actions have had a major impact on successful project completion.

Recently, Dale has contributed to research evaluations and has guided program scientists in a number of areas, including the upgrade to dual polarization, analysis of increased data resolution and mitigation of range velocity ambiguities. He contributed to an overview of proposed fine resolution techniques, which promise to improve detection capabilities of the radar system by employing higher resolution data collection methods (Brown 2005). Over the past several years, he was called upon to review proposed methods for increasing the effective number of range samples and also has provided tutorials covering polarization diversity. He continues to advise ROC engineers developing range velocity mitigation techniques for near term deployment in the ORDA environment and recently provided guidance on spectrum width data quality control.

CONCLUSIONS

Dale Sirmans' career in Doppler weather radar has spanned parts of five decades. Along the way, he contributed to virtually every technical discipline necessary for the success of the NEXRAD program. Dale continues to motivate others, his style is always to quietly support and guide his colleagues, ensuring their success. Individuals who have been his associates, including the authors of this paper, are universally grateful for the opportunity to learn from him. We all look forward to many more years of working with Dale as we move forward into an era of opportunities for improving the WSR-88D network and the discipline of weather radar in general.

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