P1.21 PATH TO NEXRAD: DOPPLER RADAR DEVELOPMENT AT THE NATIONAL SEVERE STORMS LABORATORY DURING THE 1960s AND 1970s

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1. INTRODUCTION

In 1959, 31 people lost their lives in an airplane accident that occurred over Maryland. The fuel tanks in the Viscount aircraft were struck by lightning and the resulting explosion and fire led to the fatal crash. This event and several other aircraft accidents associated with severe weather led to the creation of the National Severe Storms Project (NSSP) in 1961, headquartered in Kansas City, MO. One of the field observation sites, called the Weather Radar Laboratory, was placed in Norman, OK in 1962. In 1963, a decision was made to transfer the entire NSSP operation to Norman, where it was reorganized as the National Severe Storms Laboratory (NSSL). Not only was the operation of NSSP transferred, but a larger mission was envisioned by the new U. S. Weather Bureau (USWB) Chief, Robert White. This mission would include the development of more sophisticated radar processing and display systems in support of operational needs of the USWB. Edwin Kessler was appointed the Director of NSSL.

The early success of USWB employees David Holmes and Robert Smith in the detection of a tornado over El Dorado, Kansas in June 1958 stimulated interest in the use of Doppler radar (Smith and Holmes 1961). These meteorologists had used a 3-cm wavelength continuous wave (CW) Doppler radar that had been obtained from the U. S. Navy and modified at Cornell Aeronautical Laboratory. The idea and design of the radar was attributed to electrical engineer James Brantley. Rogers (1990) has presented a detailed description of the post-World War II work that led to Doppler weather radar by the mid- to late-1950s.

In this historical paper, we follow the steps of several NSSL engineers that led to the development of the 10-cm wavelength Doppler radar that became the prototype for the current NEXRAD (NEXt generation weather RADar) or WSR-88D (Weather Surveillance Radar-1988 Doppler) Network.

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2. KESSLER AND LHERMITTE: DOPPLER RADAR COMES TO NORMAN

Prior to his arrival at NSSL, Edwin Kessler was a research meteorologist at Travelers Research Center (TRC) in Hartford, Connecticut. He had acquaintance with weather radar, but his specialty was the kinematics of precipitation associated with convective clouds–an outgrowth of his dissertation work at the Massachusetts Institute of Technology (Sc. D. 1957).

Letters from the TRC files indicate that Kessler was working with the USWB in 1963 on issues related to weather radar. The planned role of radar in USWB operations was expressed by Bigler et al. (1962) as follows:

> Weather radar data [should] be integrated into forecasting, warning, and briefing activities, and that a system be devised to provide these data in digitized form for computer processing and as composited pictures at major airports.
>
> That research be pursued to develop techniques for integrating radar into the weather measurement systems, and for obtaining quantitative information from radar displays.

Kessler submitted a proposal to the USWB on 3 April 1963 with the intention of “. . . collecting and processing digitized radar data and other data applicable to severe storm and tornado warning and prediction . . .” (USWB Proposal 1963).

While involved in these activities at TRC, Kessler began communication with a radar engineer named Roger Lhermitte. Lhermitte had emigrated to the U. S. from France where he had recently received his doctoral degree in electrical engineering from the University of Paris. In the U. S., Lhermitte worked at the Air Force Cambridge Research Laboratories (AFCRL) outside Boston, MA.

Although Kessler did not officially become the Director of NSSL until early January 1964, he began to coordinate efforts to build a weather radar program at the lab in late 1963. In a letter to Lhermitte in September 1963, Kessler (1963) wrote that the following tasks be given top priority:

> 1. Make the CW-Doppler operate and provide improved means of recording the Doppler data.
>
> 2. Improve the accuracy and reproducibility of data recording and reduction procedures used with the WSR-57.

The CW-Doppler radar referred to in this letter is the same one that was used by Smith and Holmes, transferred from Washington, D.C. to Oklahoma.

With Kessler's commitment to developing weather radar and Lhermitte's expertise–practical and theoretical–it comes as little surprise that Lhermitte left AFCRL for NSSL in early 1964, shortly after Kessler assumed his duties as Director.

3. SUCCESS WITH DOPPLER RADAR 1964-66

At NSSL, Lhermitte was assisted by Chief Technician Walter Watts and technicians (later engineers) John Carter and Dale Sirmans (Kessler 1990). Lhermitte had an intensity in his work. He was driven, and often impatient. As remembered by Sirmans (1997-2000), "Lhermitte was removed from day-to-day operations . . . he gave me a lot of independence, but gave advice when problems arose."

Sirmans began work on the CW radar under Lhermitte's guidance. They used many of the original components of the radar, but since they wanted a pulse 3-cm radar instead of the continuous wave version, a transmitter and receiver needed to be built. This work was completed near the end of 1964. In his oral history interviews, Sirmans (1997-2000) said that he had to pull all of his previous education and experience in engineering together to complete the job. He remembers bringing Lhermitte to the trailer for a demonstration for the first time after completing the transmitter-receiver work:

> From a cold start, the system came up incoherent but became coherent when the phase lock loop was established, producing strikingly different signal displays when the system locked. Roger was immediately elated, he rubbed his hands together and said "We have a Doppler radar!"

In a far-reaching and expansive paper, Lhermitte summarized his early work at NSSL and gave his view of the future of Doppler radar in meteorology (Lhermitte 1966a). The first paragraph of this paper reads:

> Conventional radar technologies have contributed significantly to the study of precipitation physics and storm dynamics. Yet many fundamental problems would be more effectively addressed if there were information on the motion of the particles inside storms not provided by conventional radars.

In this paper he discusses the weighty issues of: preferred wavelength for the radar, with insightful discussions of the pros and cons; storing, processing and displaying the Doppler radar information; and scanning capabilities for severe storm monitoring. He concludes by stating that two types of Doppler radars are appropriate for studies of atmospheric physics: the low-power 3-cm pulse Doppler with fixed vertical beam for studying vertical motions of the air, and the 10-cm or longer wavelength radar (as cost permits) with a beamwidth of 2^o or less for a three-dimensional surveillance network.

Thus, by late 1964, NSSL had a 3-cm pulse Doppler radar system. Signal processing in this system, advanced for its time, analyzed one range location in real time (spectrum analyzer) and used analog methods to record data at 14 range locations for post analysis (Sirmans and Carter 1968). This Doppler system was used in a variety of studies relating to special problems in precipitation physics, within-storm flow fields (e.g., Peace and Brown 1968), and clear air radar returns (e.g., Lhermitte 1966b) until it was decommissioned in 1970.

4. THE IMPASSE

Just as it appeared that NSSL was on a path to developing Doppler radar capability that would "more effectively" address the problems of air motion inside storms, Lhermitte decided in late 1966 to leave NSSL. Without Lhermitte's direct input on the reasons for leaving, we can only give an incomplete picture of the situation. According to Kessler (1998), Lhermitte wanted to have three Doppler radars to ideally obtain the three-dimensional wind field in severe storms. He was very disappointed when Kessler told him that NSSL would not be building three Doppler radars.

The dilemma facing NSSL was gargantuan: should the lab halt its activity in Doppler development, should it seek a replacement for Lhermitte, or should it continue with the home-grown team minus Lhermitte. As Kessler reminisces on this subject, he still exhibits a nervousness and conveys the sense of anxiety that he felt at the time. Quoting Kessler (1998): "We decided to go ahead with our program and Dale Sirmans was put in charge. It was a tough decision . . . Yet he knew weather radar and had been mentored by Roger."

Problems were made worse when the Federal Aviation Administration (FAA) cut its support of the Doppler program. Nevertheless, Kessler took $25K from the "Director's Discretionary Fund" and allowed the work to continue. So, in early 1967, Sirmans was put in charge of the Doppler program and he had the benefit of modest support from the Director's fund.

5. 10-CM DOPPLER COMES TO NORMAN

In accord with Lhermitte's (1966a) advice to the larger community, the attenuation associated with the 3-cm radar would make it unacceptable for a severe storm surveillance radar. So NSSL made the decision to go with the more expensive 10-cm wavelength Doppler radar. With the help of NSSL Deputy Director Gilbert Kinzer and Gene Walker, a consultant from the University of Oklahoma, a surplus 10-cm radar that was part of the U. S. Air Force Distant Early Warning (DEW) Line of radars was obtained by NSSL. This radar had the basic components needed, including a klystron transmitter, that is the type of transmitter best suited for Doppler radars. However, it needed several additional components: antenna, pedestal, radar system control, signal processing, and data archive. The tower was scrounged from nearby Tinker Air Force Base. As part of a training exercise, Air National Guard groups dismantled the tower and set it up on the north campus of the University of Oklahoma where the lab was located. Thus, by early 1969, a 10-cm Doppler radar resided at NSSL, ready to be upgraded.

When the radar became operational during the middle of the 1971 spring tornado season, it was one of the few 10-cm Doppler radars in the world. At that time, the only type of real-time Doppler velocity display was the velocity shear display used on the AFCRL radar (Armstrong and Donaldson 1969). The NSSL radar did not have a real-time display. Instead, time-series data were recorded on tape at a set of 16 range locations that could be stepped out on consecutive sector scans to encompass storms of interest. Researchers could not see Doppler velocity fields until days, weeks, or even months later. First, a Fast Fourier Transform had to be run to transform the time-series data into the Doppler velocity spectrum from which mean Doppler velocity and spectrum width values could be computed. The Doppler radar data then were printed out in "B-scan" format (range vs azimuth) for analysis.

6. DOPPLER RADAR AS POTENTIAL WARNING TOOL

The first severe storms captured by the 10-cm radar were on 23 May 1971 (Brown and Crawford 1972) and 2 June 1971 (Brown et al. 1971). The first tornadic storm was the Davis, OK, tornadic storm on 19 April 1972 (Brown et al. 1973; Burgess 1974). However, the storm event that forever relieved any doubts about the potential value of Doppler radar as an operational warning tool was the Union City, OK, tornadic storm that occurred on 24 May 1973.

The tornado that struck Union City was not only well documented by Doppler radar (Brown et al. 1978; Donaldson 1978), but also through photographs (e.g., Golden and Purcell 1978). Thus, timing and location of the tornado was well known. The Doppler velocity tornadic vortex signature (TVS)–first discovered in this storm–formed aloft about 25 min before tornado touchdown, descended to the ground as the visible tornado formed, reached its maximum strength and maximum vertical extent when the tornado was widest, and disappeared as the tornado lifted. This was a dramatic indication that the evolution of a TVS mirrors the evolution of the associated tornado.

Since the TVS works best as a signature for larger tornadoes that are closer to the radar, the tornado's parent mesocyclone was investigated as a potential precursor for tornado formation. Burgess (1976) presented statistics for 37 mesocyclones that were observed on severe storm days by NSSL Doppler radars from 1971 through 1975. Two-thirds of the mesocyclones had tornadoes associated with them and the average lead time from initial detection of the mesocyclone (in data analyzed after the fact) and tornado touchdown was 36 min.

7. PATH TO NEXRAD

The National Weather Service (NWS) and U. S. Air Force's Air Weather Service (AWS), who were ready to replace their respective aging conventional radar networks, were impressed with these research findings. So, they decided to undertake an operational experiment to determine whether the addition of Doppler capability would improve the accuracy and timeliness of severe storm and tornado warnings. The experiment was called the Joint Doppler Operational Project, or JDOP (Staff 1979).

Two technological advances during the late 1960s and early 1970s made it possible to display Doppler velocity data in real time. The first was the pulse pair processor, which permits mean Doppler velocity and spectrum width data to be computed in real time from pairs of pulses (e.g., Rummler 1968), instead of running a Fast Fourier Transform to compute the Doppler velocity spectrum from the time-series data. The second advance was the development of color monitors, which permit the display of fine-resolution Doppler radar data that is not possible on a black-and-white display.

JDOP was conducted during the spring tornado seasons of 1977 and 1978 using the NSSL Norman Doppler radar, with additional equipment provided by the Air Force Geophysics Laboratory (AFGL). The NWS, AWS, FAA, and NSSL participated in JDOP. Results of the experiment were evaluated by comparing warnings issued by the NWS forecast office in Oklahoma City with advisories issued by the JDOP team. In general, for both severe storm and tornado warnings, there was a noticeable increase in the probability of detection and a marked decrease of false alarms. The tornado lead time increased from -1 min using conventional radar and spotters to +21 min using Doppler velocity information (Staff 1979).

Based on the success of JDOP, the NWS, AWS, and FAA established in 1980 the Joint System Program Office in Washington, D.C. to oversee the procurement of the 10-cm NEXRAD (ultimately called the WSR-88D) for a national network of Doppler radars. Design of the radar closely followed what Sirmans had developed for the NSSL Doppler radar in Norman.

8. DISCUSSION

The driving force behind the development of NEXRAD was a coupling between research and operations. From the beginning, NSSL had a mission statement that linked weather radar research with the needs of operational forecasters. Issues such as advanced warning of severe weather were always at the forefront of the lab's efforts, yet research that led to fundamental understanding of the severe storm–especially the tornadic storm–was a byproduct of this coupling. Without doubt, Roger Lhermitte's vision and research strength were crucial to Doppler radar development at NSSL. His mentorship during the period 1964-1966 sustained the effort after his departure. Much credit must also be given to Edwin Kessler for the tenacity he exhibited in the face of losing Lhermitte, and the added burden of a shortfall in research funds for further development of the radar. And finally, Dale Sirmans, Lhermitte's protégé, accepted the responsibility of leading a team of engineers that successfully developed the 10-cm radar that became the cornerstone of NEXRAD.

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