AD-A177 120 MESOSCALE ST DOPPLER RADAR MEASUREMENTS AT PENNSYLVANIA STATE UNIVERSITY..(U) PENNSYLVANIA STATE UNIV UNIVERSITY PARK DEPT OF METEOROLOGY D W THOMSON 1/1

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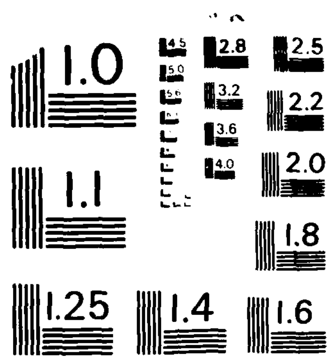

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With substantial financial assistance from the USAF Office of Scientific Research, the Department of Meteorology at Penn State University has constructed and installed three clear-air Doppler ST "Profiler" radars. Two of the radars (VHF) operate at approximately 49 MHz, the third (UHF) at about 405 MHz. The VHF systems are now permanently installed near McAlevey's Fort and Crown, Pennsylvania, respectively. The UHF is a portable system which can be either deployed easily for use in diverse field experiments or operated as a part of a three system mesoscale network enclosing central and west central Pennsylvania. The final report summarizes the development of this unique facility, the operating performance of the various units, the application of the radars to scientific problems of general and special interest to the Air Force, and the impact and importance of the operating radars on the graduate education and research program in the Department of Meteorology. With respect to the latter the importance of the impact cannot be overstated: the availability of the radars and the

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MESOSCALE ST DOPPLER RADAR MEASUREMENTS AT PENNSYLVANIA STATE UNIVERSITY

FINAL SCIENTIFIC REPORT

AFOSR -83-0275

1 October 1986

Dennis W. Thomson
Department of Meteorology
The Pennsylvania State University
University Park, PA 16802

87 2 13 120

Table of Contents

I. Introduction

With substantial financial assistance from the USAF Office of Scientific Research (Grant AFOSR-83-0275) the Department of Meteorology at Penn State University has constructed and installed three clear-air Doppler ST "Profiler" radars. Two of the radars (VHF) operate at approximately 49 MHz, the third (UHF) at about 405 MHz. The VHF systems are now permanently installed near McAlevey's Fort and Crown, Pennsylvania, respectively. The UHF is a portable system which can be either deployed easily for use in diverse field experiments or operated as a part of a three system mesoscale network enclosing central and west central Pennsylvania.

This report summarizes the development of this unique facility, the operating performance of the various units, the application of the radars to scientific problems of general and special interest to the Air Force, and the impact and importance of the operating radars on the graduate education and research program in the Department of Meteorology. With respect to the latter the importance of the impact cannot be overstated: the availability of the radars and the observations they are routinely providing has been an event comparable to or greater in importance to the availability in the Department of the first satellite imagery more than two decades ago.

II. Technical Specifications of the Radars

At the time this project was started there were no commercially available such radars. To no small extent some of the subsystems which were first constructed for the Penn State radars have since become recognized as the prototypes for commercial units which are now available and being purchased by several national agencies including the National Weather Service, the Department of Defense and the National Aeronautics and Space Administration. Funding to purchase and install radars is being sought by a number of other major research universities in the U.S. and Europe.

In this regard it is worth noting that because various manufacturers were anticipating a later market for systems in the atmospheric sciences community, industry management underwrote a major portion of the research and development costs for subsystems ordered by Penn State. The University was thus able to purchase many parts of the radars at virtually component cost. Depending upon the details of individual systems, the unit price for a commercial system today is roughly three to fourfold the cost of each system which was installed in the Penn State network.

Each radar may be viewed as consisting of a number of major subassemblies. By subassembly Tables I and II summarize the sources and methods used to construct the two VHF and the UHF radars. As is clear in the tables many of the construction activities were, in the best sense of the word, cooperative. During all phases of the project personnel assistance, technical information, test equipment, etc., was freely exchanged between the university, the Wave Propagation Laboratory[1], (WPL), and Tycho Technology, Inc., the supplier of many of the essential radio frequency subsystems. For example WPL provided major software assistance to Penn State, and Penn State has in return provided copies of all recorded data to WPL so that it could be used for studies evaluating system

[1] National Oceanic and Atmospheric Administration/Environmental Research Laboratories

performance in the weather conditions which are characteristic of the mid-Atlantic, east coast states. NOAA/NWS has recently contracted for the construction of the first 30 profiling radars which are expected to become the nucleus of a national network for the weather service.

Tables III and IV summarize the technical characteristics and nominal operating values for the VHF and UHF radars, respectively.

The two VHF radars have been permanently installed near McAlevey's Fort and Crown, Pennsylvania, respectively, and have been in essentially continuous operation since. Operating performance and reliability has in every respect exceeded specifications (and expectations). During early operation the principal causes for data outages were the result of either local powerline outages or communications failures resulting from overload in the multi-tasking, multi-use departmental computer which is used for data communication and archiving. All but extended powerline outages were mitigated by installation of a "May-Day" emergency power supply on each radar. The data communications problem was solved when the departmental machine used for that purpose was upgraded from a DEC PDP 11/34 to VAX 8200.

Table I: Construction of the Two VHF Radars

Subassembly	Design	Fabrication	Installation
Field Site Preparation	PSU	PSU	PSU
Antenna	WPL-Tycho	Tycho	PSU-Tycho
Transmitter	Tycho	Tycho	Tycho-PSU
Receiver	Tycho	Tycho	PSU
Time Domain Integrator	WPL	PSU	PSU (Testing at WPL)
Signal Processing Computer	WPL-PSU	Data General/PSU	PSU
Signal Processing Software	WPL	WPL	PSU
External Communications	PSU	PSU	PSU
Data Display and Archiving	PSU	PSU	PSU

Table II: Construction of the UHF Radar

Subassembly	Design	Fabrication	Installation
Field Site Preparation	(system portable; initial operation at Rock Springs, PA, and Marshall Space Flight Center, AL)		
Antenna[1]	Tycho	Tycho	PSU
Transmitter	Tycho	Tycho	PSU
Receiver	Tycho	Tycho	PSU
Time-Domain Integrator	WPL	PSU	PSU
Signal Processing Computer	WPL-PSU	Data General/PSU	PSU
Signal Processing Software	WPL	WPL-PSU	PSU
External Communications	PSU	PSU	PSU
Data Display and Archiving	PSU	PSU	PSU

[1] World's first 400-406 MHz band Co-Co Type

Table III: Characteristics and Operating Values for the VHF Radars

Characteristic		Value	
Radar			
	Frequency	49.8 and 49.92 MHz	
	Bandwidth	300 KHz or 100 KHz	
	Peak Power: operating	≃ 28 KW	
	maximum	≃ 30 KW	
	Pulse Length	3.67 or 9.67 μsec.	
	Pulse repetition period	238.67 or 672 μsec.	
Antenna			
	Type	Orthogonal phased arrays, colinear-coaxial dipoles	
	Aperture	50x50 m	
	Pointing Angles	Vertical and 14.72° orthogonal off zenith	
	Beamwidth (2 way)	≃ 4°	
Data Processing		3.67 μ sec.	9.67 μ sec.
	Time domain averaging	400 pulses	125 pulses
	Spectral averages	8	16
	Maximum radial velocity	±15.7 $m \cdot sec^{-1}$	±19.6 $m \cdot sec^{-1}$
	Spectral (velocity) resolution	0.49 $m \cdot sec^{-1}$	0.31 $m \cdot sec^{-1}$
Height Range and Resolution			
	Mimimum height	≃1.02 km or	1.11 km
	Height resolution	290 m	870 m
	Number of heights reported	24	18
	Maximum height (agl)	6.78 km	16.77 km

Turn on Date: McAlevey's Fort 28 June 1985
Crown 21 April 1986

Table IV: Characteristics and Operating Values for the UHF Radar

	Characteristic		Value		
Radar					
	Frequency:	initial operation	405.25 MHz		
		requested	404.37 MHz		
	Bandwidth		1 MHz, 300 KHz or 70 KHz		
	Peak Power:	operation to date	10 KW		
		post modification	30 KW		
	Pulse lengths		3 or 9 μ sec.		
	Pulse repitition periods		100, 200 or 300 μ sec.		
Antenna					
	Type		Orthogonal phased arrays, colinear-coaxial dipoles		
	Aperture		6 .1 x 7.6 m		
	Pointing angles		Vertical and 14.47° orthogonal off zenith		
	Beamwidth		≃ 4°		
Data Processing			1 μsec	4 μsec	16 μsec
	Time domain averaging		112	70	35 pulses
	Spectral averages		16	32	64
	Maximum radial velocity		±18.25 m·sec^{-1}		
	Spectral (velocity) resolution		0.29 m·sec^{-1}		
Height Range and Resolution					
	Minimum height (agl)		400 m, 100 m possible		
	Height resolution		100 m	300 m	800 m
	Number of heights reported		24	24	14
	Maximum height (agl)		2800 m	7600 m	11.6 km

Turn on date: 28 April 1986

III. Research Applications in Progress

The breadth of application for the new radars is enormous. Already, the new measurements are being used in applications ranging from characterization of fine-scale structure parameter profiles and the generation and dissipation of clear-air turbulence to meso-and synoptic scale definition of evolving storm systems. Recall that conventional observations are available at only 12 hour sampling intervals. The radars are providing new wind profiles as frequently as every two minutes. In a special study of gust-fronts which are particularly hazardous to the landing aircraft, the sampling interval on the UHF system was cut to only 25 seconds.

Table V summarizes some of the capabilities and applications of the radar network capabilities and applications of the radar network. The various matrix elements define signal parameters and also the network or external data requirements, if any, for a particular application. When compared to many presently used atmospheric profiling techniques, the radars offer advantages not only in temporal resolution but also in vertical resolution, range and accuracy. The systems are ideal for diurnal, seasonal and climatological studies as well as realtime output and intensive research applications. The contents of Table V are only generally defined. Many additional topics for research may be implied by a single subject. For example, the application "diffusion coefficients" is relevant to chaff dispersal, fallout, CBW, tropospheric pollution, long range transport and diffusion of acidic contaminents, volcanic dust dispersion and ozone depletion.

The availability of the radar measurements has been an essential component in expanding departmental research programs concerned with mesoscale and sub-mesoscale phenomena. Almost one-half of the resident faculty and research staff are already directly dependent upon new measurements being

Table V. Penn State VHF Doppler Radar Network: Measurements and Applications. Matrix elements represent parameters or phenomena of interest. All measurements are available as a function of height and time.

Basic Data	Doppler Shift	Doppler Spectrum	Received Power
Direct physical relation	$\bar{u}, \bar{v}, \bar{w}$	$\sigma_u, \sigma_v, \sigma_w$ $\frac{\Delta u}{\Delta z}$ $\frac{\Delta v}{\Delta z}$ $\frac{\Delta w}{\Delta z}$	C_N^2 (radar) Communication system performance (tropo-scatter, etc.)
Derived from above	Shear Wave motions Velocity spectra	Disipation TKE Inner scale of turbulence Diffusion coefficients Clear air turbulence	Tropopause height
Above plus supplementary radiosonde data	Richardson number Clear air turbulence		C_N^2 (optical) C_{eT} (covariance)
Radar network	Mesoscale divergence Coherence (e.g., "patches of turbulence") Speed and direction of gravity waves Jet stream structure Frontolysis		Parameterization of structure parameter profiles Optical systems performance
Radar plus synoptic network and numerical analysis and prediction	Mesoscale and storm systems; structure and evolution Initialization and performance of mesoscale models		Loc. cit. above Parameterization . . . and Optical . . . Evaluation of systems performance parameters

provided by the radars for use in contract research programs. Table VI summarizes basic data regarding the major research programs now in progress for which radar measurements are an essential part.

Air Force involvement and utilization of the radars through research programs such as the structure parameter studies has already been extensive. A comprehensive field program of radar, optical, acoustic and in-situ structure parameter measurements conducted in May, 1986 at State College included participation by scientists representing three Air Force laboratories: AFGL (Good and Brown), RADC (Charnocky and Stebbins), AFWL (Walters of the Naval Postgraduate School and Davidson). Facetiously referred to as EWAK (Experiment without Akronym), the field measurements now being analyzed are, probably, one of the most comprehensive and highest quality structure parameter data sets which has ever been assembled.

Papers presenting preliminary results of the radar measurements have already been presented at the two most recent MST Radar Workshops at Champaign, IL in 1984 and Arecibo, Puerto Rico in 1986. A paper presenting preliminary results relevant to air traffic applications was given by G.S. Forbes at the IInd International Conference on Aviation Weather Systems, in June 1985 at Montreal, Canada.

Four scientific papers are now in preparation for submission to the refereed journals Monthly Weather Review and Atmospheric and Oceanic Technology.

Table VI

"Long Term Studies of the Refractive Index Structure Parameter in the Troposphere and Stratosphere."
Sponsor: Air Force
Contract No.: AFOXR-86-0049
11/15/85 - 11/14/86
$146,419

"Dry Deposition Monitoring and Research."
Sponsor: USDC
Contract No.: NA815-OC-C-06145
5/1/86 - 4/30/87
$92,731

"Investigation of the Mesoscale STructure of Northeastern United States Weather Systems and the Development of Short-Term Forecast Techniques Using a Network of Doppler."
Sponsor: Air Force
Contract No.: F19628-86-C-0092
7/7/86 - 10/6/88
$214,899

"Combined VHF Doppler Radar and Airborne (CV-990) Measurements of Atmospheric Winds on the Mesoscale."
Sponsor: NASA
Contract No.: NAG8-050
10/1/85 - 9/30/86
$49,877

"The Marine Atmosphere on the Fleet Scale."
Sponsor: Department of the Navy
Contract No.: SFRC No. N00014-86-0688
8/15/86 - 8/14/91
$7,417,629

"Investigations of the Mesoscale Structure of Northeastern United States Weather Systems and the Development of Short-Term Forecast Techniques Using a Network of Doppler Radar Wind Profilers."
Sponsor: Air Force
Contract No.: F19628-86-R-0026
5/1/86 - 4/30/88

IV. Impact on Graduate Research Program.

During the last 25 years, two technological advances have particularly impacted on the nature and quality of meteorological research and teaching programs at most major U. S. universities. The first was the capability to receive in realtime satellite imagery for use in weather analysis and forecasting applications. Secondly, has been the now widespread use of local sophisticated mini- and microcomputer systems which has greatly facilitated the processing of operational data for aiding interpretation and facilitating effective visual display.

At Penn State we now have in routine operation a third equally profound technological advance; the profiler radar facility. The radars are providing, continuously, never before available measurements of tropospheric and stratospheric winds and structure on a time scale providing temporal resolution which is 360-fold that of the conventional (12 hour) upper air observations.

In addition to enhancing the departmental research program this new technology has resulted in the development of several new graduate and undergraduate courses and altering the content of several others. An existing graduate course in remote sensing, Meteo 536, is now essentially entirely devoted to profiler science. A new graduate seminar course is being developed to follow national and international profiler science as the technology is now being installed at a number of national laboratories and other universities. Recognizing the profound implications of profiler measurements for a broad spectrum of meteorological problems, no less than 30% (6) of the resident faculty participated in the last (Fall, 1985) 536 course. The profiler measurements are also already being used in introductory (Meteo 414) and advanced (Meteo 597) mesoscale analysis and forecasting courses. By early

1987 as many as 25% (16-18) of our resident graduate students will probably be depending if not directly at least peripherially on profiler-based measurements for their graduate thesis study programs. Table VII summarizes the profiler-based graduate thesis studies already in progress. It is worth noting that Moss is an AFIT Ph.D. whose post-graduate study assignment to the Air Force Weapons Laboratory is already in progress.

Table VII: Profiler-Based Thesis Studies is Progress

1. Bekermeier, Jean, M.S., "Studies of Mesoscale Belts of Wind Maxima."

2. Carlson, Catherine A., M.S., "Kinematic Qualities Derived from UHF and VHF Doppler Radar Wind Profiler Data."

3. Carroll, L. A., M.S., "Gusts Fronts as Seen by 400 MHz Wind Profiler."

4. Hemler, Michael G., M.S., "Doppler Wind Profiler Examination of Cloud Edges."

5. Knowlton, Larry, M.S., "Frontal Circulations Derived from Dual and Triple-Profiler Methods."

6. Moss, Michael T., Ph.D., "Measurement and Modeling of Tropospheric/Stratospheric Refractive Index Structure Parameter."

7. Neiman, Paul, M.S., "Thermodynamic Parameters Derived from Single Wind Profiler Data."

8. Syrett, William J., M.S., " Profiler Radar Data Drop-outs in the Vicinity of the Jet Stream."

Acknowledgements

From concept to completion the encouragement and assistance of Dr. C. Gordon Little, Director of NOAA's Wave Propagation Laboratory has been of critical importance to the development of this new radar facility. We are also deeply indebted to his associates at WPL Dave Merritt, Ken Moran and Dick Strauch for their engineering and technical assistance during many stages of the system development work.

At Penn State neither the individual radars nor the network could possibly have been assembled, installed, tested or operated without the dedicated and outstanding assistance provided by Rob Peters, Scott Williams and Jim Breon. Rather than risk not naming all of the graduate students who willingly assisted in many of the activities related to installation and testing of the radars, we want to simply remind them that we sincerely appreciate their individual and collective contributions.

A facility of this magnitude cannot be assembled in a university without at least the moral support of the entire department's faculty. In that respect success could not have been achieved without the special working environment that exists in the Department of Meteorology at Penn State. Special assistance beyond the call of duty was provided by at different times by my colleagues Chris Fairall, Greg Forbes and Charles Hosler; their respective contributions were essential and are deeply appreciated.

Finally, we are deeply indebted to Dr. John Brosnahan and his associates at Tycho Technology for their assistance in ensuring that the technical specifications and performance of many of the radar subsystems did not simply "meet" but rather always "exceeded" both our specifications and expectations.

About two-thirds of the funding, not including personnel costs, for the development of the radar facilities was provided by the USAF Office of

Scientific Research as a part of the DoD University Research Instrumentation Program. The remaining hardware funds were provided by the University through the Office of the Vice President for Research and Graduate Studies and the Dean of College of Earth and Mineral Sciences. Personnel costs associated with administration of the grant and assembly, installation and testing of the radars were contributed by the Department of Meteorology.

END

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