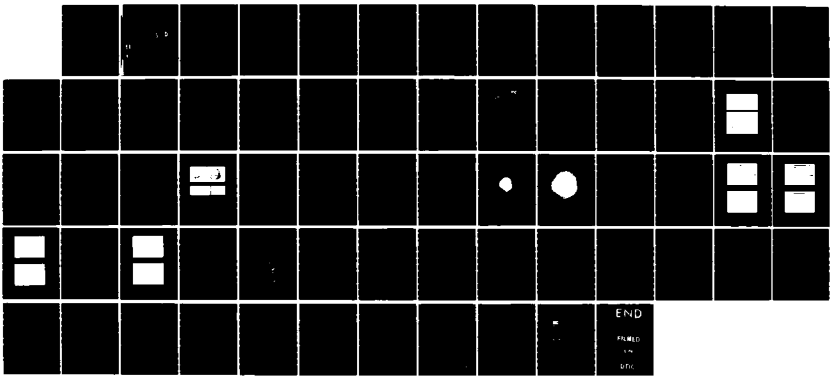
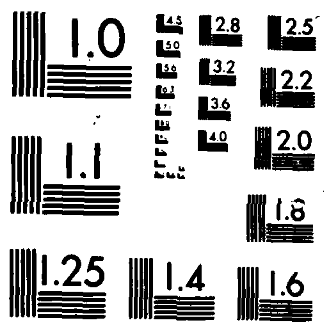
AD-A164 426 THE BOSTON AREA NEXRAD (NEXT GENERATION WEATHER RADAR) DEMONSTRATION (BAND)(U) AIR FORCE GEOPHYSICS LAB HANSCOM AFB MA D E FORSYTH ET AL. 08 MAY 85 1/1

UNCLASSIFIED AFGL-TR-85-0098 F/G 4/2 NL





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AFGL-TR-85-0098
ENVIRONMENTAL RESEARCH PAPERS, NO. 912

The Boston Area NEXRAD Demonstration (BAND)

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8 May 1985

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ATMOSPHERIC SCIENCES DIVISION PROJECT 2781
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA 01731

NEXRAD JOINT SYSTEM PROGRAM OFFICE
SILVER SPRING, MD 20900

"This technical report has been reviewed and is approved for publication"

FOR THE COMMANDER

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Atmospheric Sciences Division

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SECURITY CLASSIFICATION OF THIS PAGE

AD-A164426

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFGL-TR-85-0098 ERP, No. 912

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Air Force Geophysics Laboratory

6b. OFFICE SYMBOL *(If applicable)*: LYR

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS *(City, State and ZIP Code)*: Hanscom AFB Massachusetts 01731

7b. ADDRESS *(City, State and ZIP Code)*:

8a. NAME OF FUNDING/SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL *(If applicable)*:

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State and ZIP Code)*:

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
63707F	2781	01	00

11. TITLE *(Include Security Classification)*: The Boston Area NEXRAD Demonstration (BAND)

12. PERSONAL AUTHOR(S): Douglas E. Forsyth, Maj, USAF;* Michael J. Istok;* Timothy D. O'Bannon;* and Kenneth M. Glover

13a. TYPE OF REPORT: Scientific Final

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT *(Yr., Mo., Day)*: 1985 May 8

15. PAGE COUNT: 68

16. SUPPLEMENTARY NOTATION:

*NEXRAD Joint System Program Office

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*

Weather radar
Doppler weather radar
Operational meteorology
Automated meteorological techniques
Severe storm forecasts

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The Boston Area NEXRAD Demonstration (BAND) was formulated to assess the operational utility of Next Generation Weather Radar (NEXRAD) algorithms and display products in three seasons of New England weather. BAND was a cooperative effort which utilized the AFGL 10 cm Doppler weather radar and data processing systems and the staff of the NEXRAD Interim Operational Test Facility to remote NEXRAD-like weather radar products to future joint agency users of this data. Operational users of BAND information included both central forecast facilities such as the USAF Global Weather Central at Offut AFB, NE and the National Severe Storm Forecast Center at Kansas City, MO, as well as local forecast facilities including the Base Weather Station at Pease AFB, NH, the National Weather Service Forecast Office at Boston, MA, and the Federal Aviation Administration Air Traffic Control Center at Nashua, NH. The BAND demonstration began on 16 November 1983 and ended on 1 July 1984. During this period more than 450 hours of NEXRAD-like data on all types of New England weather were provided in real-time to the operational users for their evaluation. (Contd)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Kenneth M. Glover

22b. TELEPHONE NUMBER *(Include Area Code)*: (617) 861-4405

22c. OFFICE SYMBOL: AFGL/LYR

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

19. (Contd)

In this report, the performance of the NEXRAD algorithms in the variety of weather conditions encountered in the demonstration is summarized along with descriptions and evaluations of the NEXRAD-like products disseminated to the operational offices. Results show that NEXRAD algorithms will produce useful products in the East Coast weather environment and that the formats of most of the NEXRAD-like products are suitable for routine operational use. The acceptance levels of the products and the accuracies of the algorithms at the completion of the BAND program were judged to be above 75 percent. Findings from post analysis have suggested changes to the algorithms which should raise performance levels to at least 85 percent by the end of the validation of the NEXRAD design.

Preface

The authors are indebted to the many meteorologists and engineers who contributed to the success of the BAND program. In particular, special thanks are due Ken Wilk, Chief of the NEXRAD IOTF, for his constant encouragement, support, and counsel throughout all phases of the program. Special thanks are also due the staff of the Ground Based Remote Sensing Branch, AFGL, for their fine technical support during BAND operations, and special thanks go to Bill Smith, Graham Armstrong, and Al Bishop for keeping the equipment in excellent condition and for their dedication during extended work shifts. We also thank Ralph Donaldson for his helpful discussions and comments, Roland Boucher for his forecasting support, and Pio Petrocchi, Jim Wieler, Ian Harris, and Frank Ruggiero for their computer support. The authors also gratefully acknowledge the superb secretarial support provided by Chris Carter of the IOTF and Donna Velardi of the AFGL during the conduct of the BAND and the preparation of this report. A special note of appreciation also goes to Joan Kimpel of the National Severe Storms Laboratory for her superb preparation of many of the illustrations used in this report. A special thanks goes to all of the fine men and women at each of the offices that participated in the program and especially to Major Rod Snell, Deputy Director of the NEXRAD JSPO (DOD), Major Mike Haas and his staff at the Pease AFB Weather Station, Tom McGuire and Jim Sims of the Boston WSFO, Craig Goff of FAA Headquarters, Greg Dietz of the CWSU at the Nashua ARTCC, Jim Evans and John DiStefano of MIT Lincoln Laboratory, Lt Col Roger Whiton, Lt John Murphy and TSGT Terry Landsvork of the AF Global Weather Central, and Dick Livingston and Carolyn Kloth of the National Severe Storms Forecast Center who made this demonstration possible and contributed to the improvement of NEXRAD.

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The Boston Area NEXRAD Demonstration (BAND)

1. INTRODUCTION

The NEXt generation weather RADar (NEXRAD) is a keystone in the modernization of the nation's weather observing facilities. Deployment of NEXRAD, beginning in 1988, will provide operational users of meteorological information within the Departments of Commerce, Defense, and Transportation with a Doppler weather radar system of advanced capability to meet the integrated needs of the operational weather services and aviation meteorology. A Doppler weather radar possesses all of the capabilities of its conventional counterpart for the detection and mapping of storms and also provides for the measurement of precipitation motion within the storm. Thus NEXRAD, with its Doppler capability, will have the flexibility to meet the routine observational requirements of the aging WSR-57 and FPS-77 radars in today's national network as well as to provide explicitly detailed measurements of the internal structure and motion of thunderstorms. This ability to detect and geographically locate wind related hazards such as tornadoes, gust fronts, damaging windstorms, and dangerous turbulence will be a powerful new tool for the operational meteorologist.

NEXRAD's origin can be traced to research conducted at the Air Force Geophysics Laboratory (AFGL) and the National Severe Storms Laboratory (NSSL) and to cooperative tests of Doppler technology conducted in Oklahoma during the late

(Received for publication 3 May 1985)

1970's by NSSL, AFGL, the National Weather Service (NWS), the Air Weather Service (AWS) and the Federal Aviation Administration (FAA). The Joint Doppler Operational Project (JDOP) was established to explore the transition of Doppler technology from the Laboratories to the real time operational environment of severe storm forecasting and warning. During its three year duration, the JDOP demonstrated that a Doppler radar offers significant new operational benefits for the early and accurate identification of severe storm hazards, especially tornadoes and squall lines.[1,2] Moreover, the participants concluded that the next generation meteorological radar should have a Doppler capability. Radars built to a common set of specifications should suffice to provide data basic to the needs of all users, each of which would draw on the advancing technology of data systems to provide processed materials at operating centers. Thus the diversity demanded by differing responsibilities would be provided via agency-specialized computer programs while the nation would benefit from the large capabilities and significant economies inherent in a single radar network.

The success of the JDOP experiment led the Departments of Commerce, Defense, and Transportation to jointly sponsor the procurement of a common Doppler weather radar system. In order to procure this Next Generation Weather Radar (NEXRAD) system, the Joint System Program Office (JSPO) was established in November 1979. To give NEXRAD system contractors guidance in the area of product format and to provide confidence that Government-supplied analysis techniques (algorithms) will provide NEXRAD users with operationally useful products, the JSPO established the Interim Operational Test Facility (IOTF) at the NSSL in June 1980. The IOTF was mandated to conduct operational tests and demonstrations of prototype NEXRAD products at operational field offices. In a separate action, the Air Force tasked the AFGL to develop, evaluate, and test computer algorithms required to meet the present and future specialized needs of the AWS relative to the use of the NEXRAD.

The first test of the operation utility of NEXRAD-like algorithms and display products was conducted by the IOTF in Oklahoma City, OK, during the Spring of 1983. Reflectivity and radial velocity data from the NSSL 10 cm Doppler radar were processed and analyzed in real time to produce several of the diagnostic products planned for use in NEXRAD. These products were transmitted in real time to the

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1. JDOP Staff (1979) Final Report on the Joint Doppler Operational Project, NOAA Technical Memorandum ERL NSSL-86, Norman, Oklahoma.
2. Glover, K.M., Donaldson, R.J, Jr., Wilk, K.E., and Burgess, D.W. (1979) Joint Doppler Operational Project, Proceedings of the 8th Technical Exchange Conference, AWS Technical Report AWS/TR-79-001, Scott AFB, Illinois, pp. 3-14.

Oklahoma City NWS Forecast Office and to the Tinker AFB, OK, Base Weather Station for use and evaluation by each forecast office. Details of the Oklahoma City demonstration are given in two reports that comprise the operational plans[3] and the evaluation.[4]

The Boston Area NEXRAD Demonstration (BAND) was formulated to extend the experience with NEXRAD algorithms and display products to include weather situations common to the northeastern United States in winter, spring, and early summer.[5] BAND utilized the Doppler weather radar and computing facilities of the AFGL Ground Based Remote Sensing Branch and the staff of the NEXRAD IOTF to transmit NEXRAD-like weather radar products to future joint-agency users of these data. Operational users of the BAND information included both central forecast facilities such as the NWS Severe Storm Forecast Center (NSSFC) at Kansas City, MO, the USAF Global Weather Central (AFGWC) at Offut AFB, NE, and local facilities which included the NWS State Forecast Office at Boston, MA, the AWS weather detachment at Pease AFB, NH, and the FAA Air Traffic Control Center at Nashua, NH. The NEXRAD IOTF provided each participating organization with an interactive color display terminal connected via telephone data lines to the AFGL computer. Personnel from each office were provided training in the interactive control and interpretation of the products through informal on-site training sessions conducted by the IOTF staff and a formal training session conducted at AFGL in September 1983 by the staff of the IOTF, AFGL, and Lincoln Laboratory.

The demonstration began on 16 November 1983 and ended on 1 July 1984. Approximately 450 hours of NEXRAD-like products were generated and distributed on 59 days. Approximately 5 percent of the operation was devoted to wind profiles in clear or cloudy conditions without precipitation; 28 percent was in rain showers or thunderstorms; 31 percent was in snow; and 36 percent was in widespread rain.

This report summarizes the performance of the NEXRAD algorithms in these weather conditions and describes the types of NEXRAD-like products disseminated to the operational offices. Responses of the field forecasters to the products are summarized with recommendations for changes in algorithm and product designs.

The operational value of NEXRAD-like products was determined from BAND Users' Workshops conducted during March and June 1984 and from post analysis of data archival during the most significant weather events. Results of this evaluation

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3. IOTF Staff (1983a) Plan for Spring 1983 Demonstration of Prototype NEXRAD Products in an Operational Environment, JSPO Report, Silver Spring, MD, 92 pp.

4. IOTF Staff (1984) Results of First Demonstration of Prototype NEXRAD Products in an Operational Environment, JSPO Report, Silver Spring, MD, 103 pp.

5. IOTF Staff (1983b) Plan for the Boston Area NEXRAD Demonstration (BAND) of Prototype NEXRAD Products, JSPO Report, Silver Spring, MD, 85 pp.

are used together with examples of base products to illustrate similarities and differences in Doppler weather radar information between Oklahoma City and Boston.

2. OBJECTIVES

The objectives of the Boston Area NEXRAD Demonstration were to test and evaluate NEXRAD-type algorithm and products in northeastern United States weather situations and determine:

(1) The operational usefulness of a composite hazards product showing past, present, and future positions of showers and thunderstorms, their growth trends, and the detection of hail and mesocyclones.
(2) The responses of forecasters to color display formats, product content, background maps, and keystroke control.
(3) The operational usefulness of the derived wind profiles.
(4) The adequacy of the reflectivity and base products summaries.
(5) The responses of forecasters at an air traffic control center and FAA sponsored research facilities to NEXRAD-like products.

3. HARDWARE CONFIGURATION

The AFGL 10-cm Doppler radar used in the demonstration is a dual-channel, dual-frequency, solid-state system designed to transmit, receive, and process signals simultaneously at two pulse repetition times. This design provides unambiguous reflectivity data to 460 km and usable velocity data to 230 km. The dual-frequency operation with two uniformly spaced pulse trains also allows cancellation of ground clutter, although this feature was not in operation during the BAND. In terms of key radar system characteristics such as wavelength, sensitivity, and accuracy, the performance of the AFGL Doppler is very comparable to that proposed for the NEXRAD.

Figure 1 shows the functional block diagram of the AFGL data processing, archive, and display system.[6] The pulse-pair signal processor, denoted by PPP, provides mean value estimates of reflectivity and radial velocity for each of the 768 range cells and for each one-degree half-power beam width. The data are distributed to three independently operated systems: a magnetic tape archiving system, a four-channel color display, and a Perkin-Elmer (PE) Model 3242 computer. The computer

6. Bishop, A.W., and Armstrong, G.M. (1982) A 10-cm Dual-Frequency Doppler Weather Radar, AFGL Technical Report AFGL-TR-82-0321(1), AD A125885.

is rated at 1.4 million instructions per sec, and has 2 million bytes (Mb) of memory, a 67 Mb fixed disk, two 67 Mb removable disks, a 600 line-per-minute printer, and two 9-track tape drives. A 14-track tape drive is hardwired to the radar for archiving of all spectral parameters generated by the Doppler processor. A Chromatics Model 7900 color terminal was utilized for the monitoring of products sent to the IOTF displays located at the field sites.

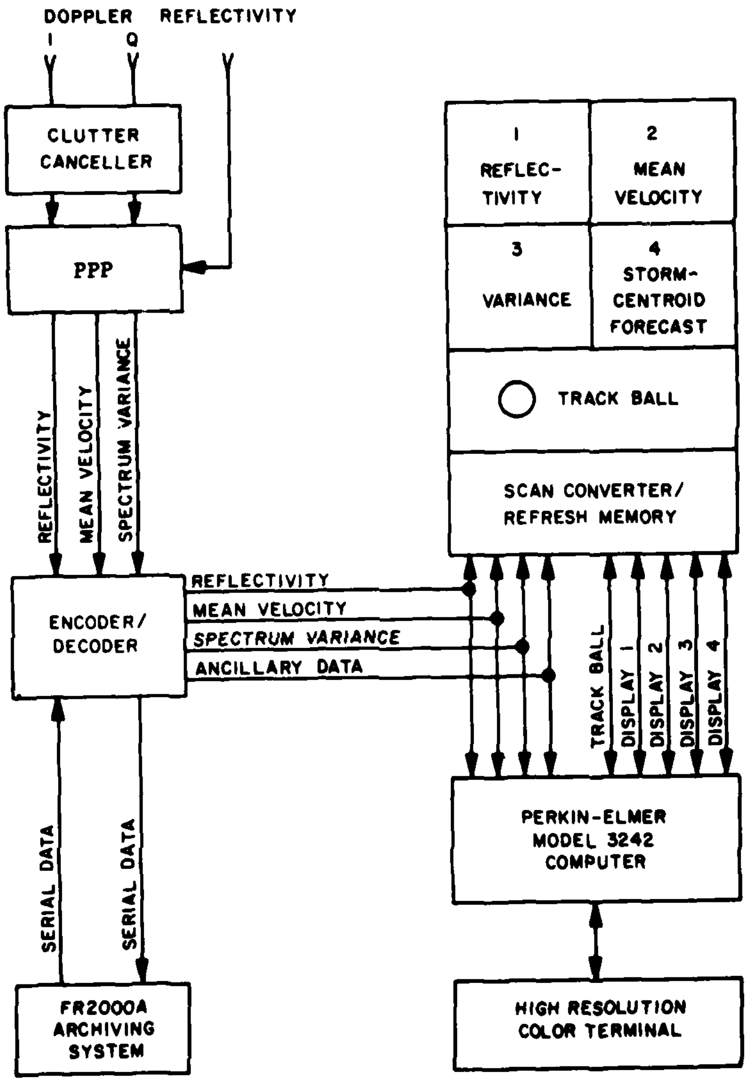

Figure 1. Functional Diagram of the AFGL Doppler Radar Data Processing, Archive, and Display System

Each field site was provided with a Chromatics (Model 1999 or Model 7900) color graphics terminal and two floppy disk drives. Each terminal was connected via a leased phone line (9600 or 4800 bps) to the AFGL PE 3242 computer, which processed and analyzed data and then communicated product images and files to each user. The product distribution is shown in Figure 2.

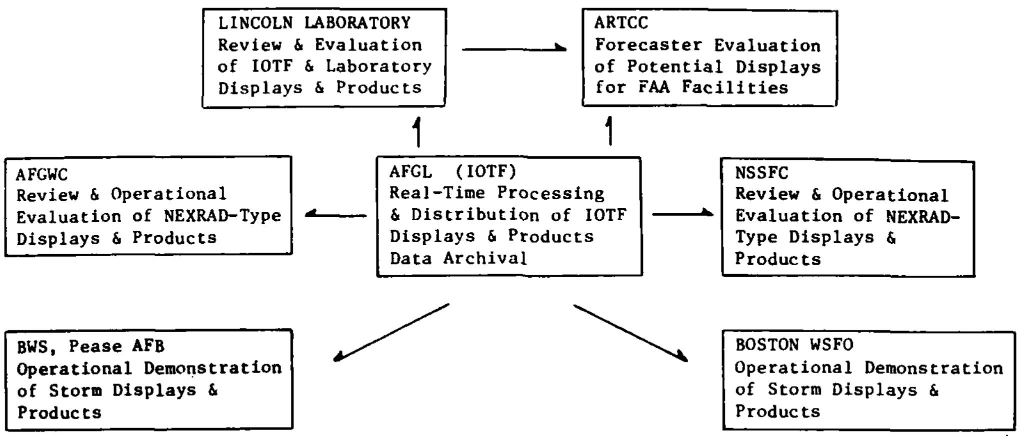

Figure 2. Product Distribution Diagram

4. SOFTWARE CONFIGURATION

After completion of the Oklahoma City demonstration, the IOTF modified the NEXRAD version of the AFGL Modular Radar Analysis Software System (MRASS) to accommodate new analysis techniques and to produce additional graphic products on the remote color displays. The echo tracking plot developed originally at AFGL was expanded to show a composite hazards product which included output from an experimental mesocyclone algorithm. This algorithm underwent several revisions during the course of the BAND program. Therefore, the algorithm test results from BAND should not, under any circumstance, be considered as representative of the performance of the currently documented NEXRAD mesocyclone algorithm. Other storm parameters (such as maximum reflectivity, height of maximum reflectivity, base and top of the 30 dBZ contour, storm mass, and height of the mass centroid) were retained as developed for the demonstration at Oklahoma City. The hail algorithm was tested with the same score weights used in Oklahoma.

The wind profiling module was altered after the March 1984 BAND Users' Workshop to produce "sectorized" wind profiles by preselecting the azimuthal limits of the data to be analyzed. This separation produced three profiles—one for each of the two sectors specified by the two angular limits, and one for the full scan, disregarding the limits. This modification was in response to a request from the forecasters at the Boston WSFO, who wanted to separate the analysis of coastal winds from inland winds, across the coastal front.

A new product was derived specifically for the Boston demonstration to summarize certain attributes of the base products not readily available in the displays of the composite hazards or the wind profiles. The IOTF operational algorithm package contains many radar product attributes that can be summarized in files and shipped fairly quickly over high-speed phone lines. A pseudo Doppler radar report (DOPREP) file was developed and transmitted late in the third period (June 1984), to AFGWC and NSSFC. It was used to generate a display locally to assist center-type forecasters in determining their needs to call for more detailed NEXRAD products.

As in the Oklahoma demonstration, the standard reflectivity (PPI) maps were not processed and transmitted because the PE 3242 computer is not adequate to produce both base and derived products. The major risk in the NEXRAD design is the performance of analysis algorithms and the appropriate display of their output. Forecaster interpretation of base products is expected to be mostly a problem of training and not one of transmission and display, which is done routinely now with the present weather radar systems.

5. DAILY OPERATIONS DURING THE BOSTON DEMONSTRATION

The Operational Plan for the Boston demonstration[5] outlines the methodology for data collection and dissemination. Routinely each morning, AFGL staff calibrated the Doppler radar, established the desired operating characteristics (antenna scan strategy, pulse repetition frequency, and so on), and performed the necessary quality control checks. The IOTF meteorologist arrived at 0700 EST to start the wind profiling algorithm. If no precipitation was observed, but there was sufficient refractive index gradient and/or cloud return to measure winds through a depth of at least 2 km, wind profiling continued for at least one hour. This produced sufficient data for later comparison with balloon wind observations being recorded 150 km southeast at the NWS rawinsonde station at Chatham, Massachusetts.

When precipitation was observed, the radar was operated in a volumetric scan mode, seven severe storm algorithms were started, and the wind profile displays were constructed. Volumetric scans were developed using continuous 360° rotation of the antenna in azimuth and discrete steps in elevation. Key parameters used in these scans were an azimuth scan rate of 85 sec per revolution and elevation angles of 0.6, 1.5, 2.4, 3.8, 4.8, 6.2, 8.2, 9.7, 11.4, and 13.0 degrees. This volumetric scan strategy was consistent with that proposed for NEXRAD; however, the use of a very slow azimuth scan rate was dictated by computer throughput rather than meteorological considerations. At the conclusion of each volume scan (10- to 15-min intervals), both types of displays were transmitted to the remote displays located at the five operational offices. During the demonstration at Oklahoma City, wind profiling was accomplished only during a pre-storm mode of operation, whereas in BAND, wind profiling continued during the development and occurrence of all types of precipitation.

The scope of the BAND operations between 16 November 1983 and 28 June 1984 is summarized in Table 1. As shown, there were 59 days of operations, with a total of 424.5 hours. Approximately 127 hours (28 percent) were during rain showers or thunderstorms; 162 hours (36 percent) in mostly stratiform rain; 140 hours (31 percent) in snow; and 23 hours (5 percent) in clear or cloudy conditions without measurable precipitation.

During the three periods of the Boston demonstration (16 NOV - 15 DEC, 10 JAN - 9 MAR, and 3 MAY - 28 JUN) there were five days of at least 20 hours of continuous operations. Severe thunderstorms occured on four days. Review of the archived data disclosed that three days (6 December, 30-31 January, and 13 June) most vividly illustrated the performance of the NEXRAD algorithms in varied northeastern weather situations experienced during the fall, winter, and spring seasons. Data and products recorded on three other thunderstorm days (23 Mar, 26 May, and 7 June) are used also to illustrate the advantages of NEXRAD processing in issuing weather warnings for the northeastern United States.

Interest in and use of the products at each of the operational offices varied greatly—depending on the time forecasters had available from their normal duties and their particular interest in the radar coverage in the area surrounding Boston. An IOTF computer program monitored all keystroke entries (product calls) made by the forecasters at each site, including the IOTF staff at AFGL. A summary of these data, sorted according to the same weather types used in Table 1, is shown in Table 2. Also shown with the total keystrokes are the daily averages and their standard deviations.

Table 1. Data Summary

Weather Type	Date	Tape Number	Hours of Operation	Date	Tape Number	Hours of Operation
Clear or Cloudy (without precipitation) 22.6 Hours	22 NOV	83-2	2.9	21 FEB	84-10	1.1
	23 NOV	83-3	2.8	23 FEB	84-10	1.5
	14 DEC	83-9	3.3	10 MAY	84-19	3.8
	16 JAN	84-2	2.1	18 MAY	84-20	1.3
	7 FEB	84-7	0.3	5 JUN	84-24	0.7
	17 FEB	84-10	1.6	13 JUN	84-25	1.2
Rain (mostly stratiform) 162.4 Hours	16 NOV	83-2	8.5	24 FEB	84-11	10.0
	25 NOV	83-3	9.2	3 MAY	84-18	3.0
	28 NOV	84-4,5	26.2	8 MAY	84-19	9.6
	13 DEC	83-9	13.3	14 MAY	84-19	5.3
	15 DEC	83-10	6.5	30 MAY	84-23	6.3
	11 FEB	84-7	6.3	31 MAY	84-24	10.5
	14 FEB	84-8	6.3	1 JUN	84-24	2.2
	15 FEB	84-8,9	12.0	18 JUN	84-27	5.2
	16 FEB	84-9	11.8	25 JUN	84-28	10.2
Freezing Rain (w/snow & sleet) 31.5 Hours	5 MAR	84-13	12.6	24 JAN	84-5	10.5
	12 DEC	83-8	8.4		---	---
Snow 140.4 Hours	2 DEC	83-5	1.4	30 JAN	84-6,7	18.6
	4 DEC	83-5,6	10.3	9 FEB	84-7	3.2
	10 JAN	84-1	24.0	27 FEB	84-11,12	28.3
	13 JAN	84-2	7.6	29 FEB	84-13	2.8
	18 JAN	84-2,3,4	26.4	9 MAR	84-15	17.8
Rain Showers 38.6 Hours	21 NOV	83-2	4.2	17 MAY	84-20	5.6
	4 MAY	84-18	3.6	21 MAY	84-21	5.8
	15 MAY	84-20	6.5	4 JUN	84-24	2.7
	16 MAY	84-20	6.1	28 JUN	84-28	4.1
Thundershowers 88.5 Hours	6-7 DEC	83-8	22.1	13 JUN	84-26	7.1
	23 MAY	84-21	13.2	14 JUN	84-27	12.2
	26 MAY	84-22	8.3	25 JUN	84-28	3.9
	29 MAY	84-23	8.4	26 JUN	84-28	5.2
	7 JUN	84-25	8.1		---	---
Total Data Hours	= 452.5					
Total Days	= 59					

Table 2. Keystroke Summary

WX Type	AFGL		Pease	Global	NSSFC	BOS	ARTCC
Clear or	323	Total	156	88	25	111	386
Cloudy w/o	(29)	(mean)	(14)	(8)	(3)	(14)	(35)
Precip.	[42]	[S.D.]	[33]	[13]	[3]	[13]	[35]
Rain		1446	572	551	197	390	273
Mostly		(85)	(32)	(32)	(12)	(33)	(15)
Strat.		[41]	[25]	[36]	[24]	[24]	[16]
Freezing		124	54	51	3	14	46
Rain		(62)	(27)	(26)	(2)	(14)	(23)
Snow		518	274	207	68	55	41
		(40)	(21)	(16)	(5)	(5)	(3)
		[37]	[27]	[30]	[7]	[10]	[7]
Rain		274	248	48	1	68	67
Showers		(39)	(35)	(7)	-	(11)	(8)
		[34]	[32]	[10]	-	[10]	[14]
Thunderstorms		1088	474	137	27	278	320
		(121)	(53)	(15)	(3)	(35)	(36)
		[53]	[45]	[19]	[5]	[22]	[19]
Total		3773	1778	1082	321	916	1133
Percent of IOTF Keystrokes		--	47	29			

The Boston WFSO did not participate during November and December, so the comparison of their use with the control IOTF meteorologists at AFGL was adjusted accordingly. The total number of product calls (3773) by IOTF meteorologists during the 59 days was about three times greater than the average total at the five operational offices. Based on earlier experiences in the Oklahoma City demonstration, this is an expected difference between staff totally dedicated to radar observations and staff subily engaged in the usual forecaster duties. However, taken "en total" the product calls at the operational offices exceeded the IOTF total by about 40 percent during the Boston demonstration.

As in the demonstration at Oklahoma City, the user with the highest percentage of product calls was the local AWS office (47 percent). We believe this was because AWS has more day-to-day contact with its customers (that is, pilot briefings) and this radar outperformed their FPS-77. Second to AWS, the meteorologists at the FAA ARTCC showed the greatest interest in the derived products. In fact, their total product call of wind profiles exceeded that by IOTF meteorologists. More detail concerning the reactions of all meteorologists at all the five operational offices is listed in Appendix A, in the summary of their responses to the questionnaires. The interpretation of their perspectives are summarized in the next section.

6. OPERATIONAL PERSPECTIVES OF THE PRODUCT DISPLAYS

The responses to key questions regarding the operational usefulness of the 6 major products were scored objectively by assigning weights (excellent = 4, good = 3, fair = 2, poor = 1) and summing the weighted responses for each of the 5 offices. The results (Figure 3) show most products were judged desirable by 75 percent or more of the forecasters. The exception was the quality control plot for the wind profiling algorithm, which few forecasters used and several did not understand.

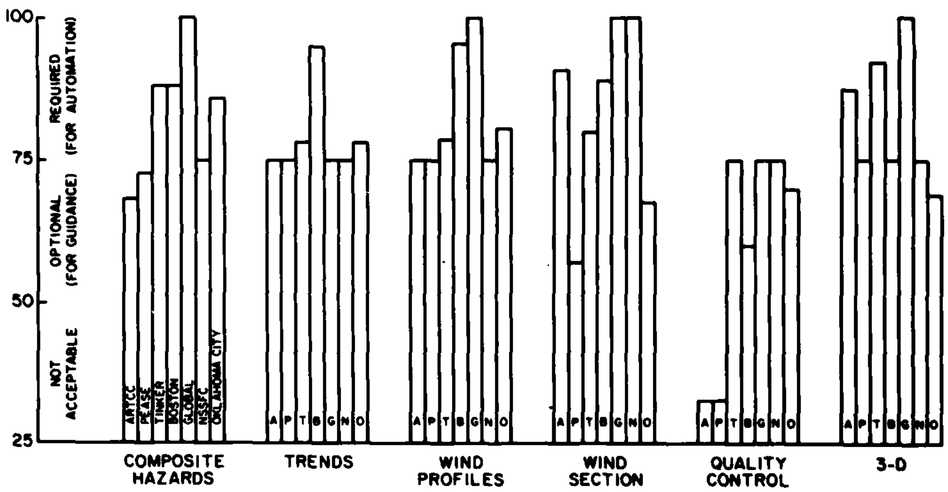

Figure 3. Summary of User Responses

Referring to Figure 3, the scores totaling less than 75 percent were mostly explained by the remarks section in the questionnaire. For example, AWS forecasters at Pease AFB disliked the wind (time) section because it was graphic and lacked detail near the ground. They would like specific numeric values for each

500-1,000 ft in the boundary layer, to advise departing and arriving aircraft. They did not use the product in synoptic analysis. However, forecasters and briefers at Pease did lead all users in the number of product calls during the Boston area demonstration. They also participated for the longest time—beginning on 16 November 1983, and ending 28 June 1984. They used the display in briefing a large number of air crews and on several occasions were able to verify NEXRAD wind profile data with measurements from KC-135 aircraft navigational systems.

While praising the wind profiles, Detachment 6 forecasters were critical of storm motion vectors, which tended to be less reliable in the non-severe showery weather regimes. This problem was noted very early at the IOTF, while examining research data previously archived. Improvements to address this problem are being investigated.

At Boston, the frequent occurrence of small cell size (at 30 dBZ) and the long time between volume scans (~ 14 min) contributed to the high error level in storm motion and extrapolation. The errors are expected to be substantially lower in the NEXRAD system.*

The FAA forecasters, like those at Oklahoma City in 1983, want the 3-D display expanded. Whenever the base data are shown, they want to see sufficient detail to determine the three-dimensional storm structure. In response to a suggestion from staff at Lincoln Laboratory, a second questionnaire was submitted showing three types of cross sections (Figure 4). All three were desired by at least one office. There was also strong support for the IOTF trends display, which is not yet an official requirement for NEXRAD.

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*NEXRAD is designed to repeat volume scans at 5-min intervals. The AFGL computer was not sufficient to process and analyze data at that rate.

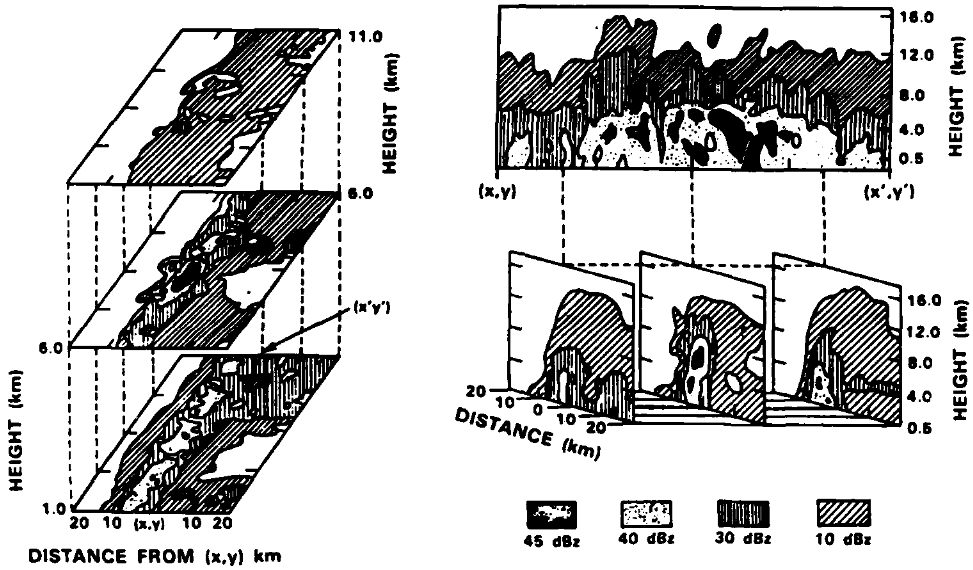

Figure 4. Types of Cross Sections Proposed by Lincoln Laboratory

Although the Boston WSFO did not participate in the demonstration until after 27 January 1984, they were instrumental in getting support data and evaluating products during specific weather events. Their post analysis evaluation memorandum prepared by the Deputy Meteorologist-In-Charge on 28 June is paraphrased here to summarize NWS forecaster views of the Boston demonstration during Part III.

> "NWSFO Boston began receiving live (thunderstorm) data in early May 1984 and participated in the demonstration until 27 June 1984. There were intermittent down-times due to line trouble or CRT (hardware) failure on about 15 days, with the most serious outage lasting from 14 June through 22 June. While no single event was a classic example of severe weather, at least four cases were noteworthy. The case selected for full documentation occurred on 23 May 1984.
>
> The product used most at the WSFO during thunderstorm activity was the Composite Hazards Product. The hail indication seemed oversensitive in that (verification) reports were not received. Hail 3/4-in. or larger is very rare in New England. However, on two days (7 and 13 June), 1/2-in. hail was verified with the hail product. The trend product display was very useful and WSFO staff recommended

that it be included as a NEXRAD product. The mesocyclone product display was interesting and potentially useful, but since tornadoes in New England are so rare, the appearance of the mesocyclone symbol merely heightened the attention of the forecasters in monitoring the severe thunderstorm, rather than convince them a tornado was about to form.

The VAD [wind profile] products were used often and, on one occasion, caused the inclusion of a low-level wind shear alert in a terminal forecast.

Most WSFO forecasters appreciated the opportunity to participate in the evaluation of NEXRAD-like products and will do so again if needed."

There was broad acceptance of all NEXRAD products at the Global Weather Central. All were graded good to excellent. Staff at NSSFC were more conservative, rating all but the wind (time) section as good. The wind (time) section (rated excellent) was used frequently by the aviation unit (NAWAU) as an aid in making low-level shear and turbulence forecasts. GWC forecasters suggest more work should be done to verify hail and tornado (mesocyclone) thresholds to "fine tune" algorithms for geographic and seasonal variations.

GWC forecasters showed more interest in the composite hazards display because of their role in issuing severe storm warnings. On the other hand, NSSFC forecasters scored the wind sections the highest because of their value in extending the rawinsonde data. Like GWC staff, they also believe the method of displaying products is superior to relaying base data because of the extraordinary time required to decipher patterns and signatures. Both centers are concerned about the future development of methods to access all of the radar information acquired from the proposed NEXRAD network.

They have agreed to continue to work with IOTF staff to develop schemes for processing, communicating, and analyzing product files to meet their future requirements.

7. EXAMPLES OF PRODUCTS DISTRIBUTED DURING THE BOSTON DEMONSTATION

7.1 Part I, 16 November to 15 December

Rainfall was abundant over New England in November and early December with most stations around Boston recording 100 to 200 percent above normal. Although none of the precipitation fell from severe thunderstorms, it was sufficiently cellular to operate the storm structure and tracking algorithms, and there was sufficient signal on most days to compute wind profiles, by the velocity-azimuth display (VAD) technique.

At the beginning of Part I, IOTF staff were concerned first with the accuracy of the products and the reliability of their reception and display at the operational offices. Since several software changes had been made to improve and extend the analysis, the processing time was expected to increase (from 8 to 14 min) with more products available, but transmitted less often. We did not expect this slowdown would be detrimental in the fall and winter storms because the precipitation patterns were expected to change slowly. However, we discovered this often was not the case. Most of the data showed small-scale convection, and analysis of the first two months of data showed only about one-half (57 percent) of the 30 dBZ cells were trackable over the 14-min volume scans. In comparison, about 75 percent of all thunderstorms were tracked.

Since point warnings of severe weather events were not needed in the winter storms, the ability to track 40-50 percent of the precipitation cells was more than adequate to summarize the general motion of the precipitation systems. In fact, in many winter storms the radar wind profiles, together with the general characteristics of the reflectivity patterns, were sufficient to follow most of the mesoscale and synoptic scale changes.

Soundings from the NWS rawinsonde station at Chatham were saved for later comparison with NEXRAD wind profiles. Figure 5 shows one of the first comparative plots of wind speed and direction recorded on 28 November 1984. In uniform wind regimes, the winds agreed very closely. In other situations, the 150 km distance between the radar and rawinsonde sites resulted in very different wind profiles. The radar profile recorded on 15 December 1983 (Figure 6), was particularly interesting because of the relatively high rms values between 2000 and 4000 feet. Although the signal strength varied with height, it is suspected that the larger values were caused by turbulence; however, the NEXRAD turbulence algorithm was not run during BAND.

Examples of base and derived wind velocity products observed in Part I are shown in Figure 7. The derived wind profiles made on 6 December 1984 and their agreement with the soundings taken at the NWS station at Chatham are shown in Figure 8. The difference in wind speed measurements in the boundary layer between the radar at AFGL and rawinsonde at Chatham is attributed to real differences in the wind field.

Wind profiles were measured daily during Part I until the IOTF meteorologists were satisfied with the accuracy and reliability of the data. As shown in Figure 9, at the 55 km range gate the vertical resolution of wind estimates was too coarse, and at 15 km ground targets biased the low-level wind estimates toward zero. Therefore, the use of the 30 km range gate at the edge of the ground pattern appeared to give the best profiles. This was the same range used in Oklahoma in 1983.

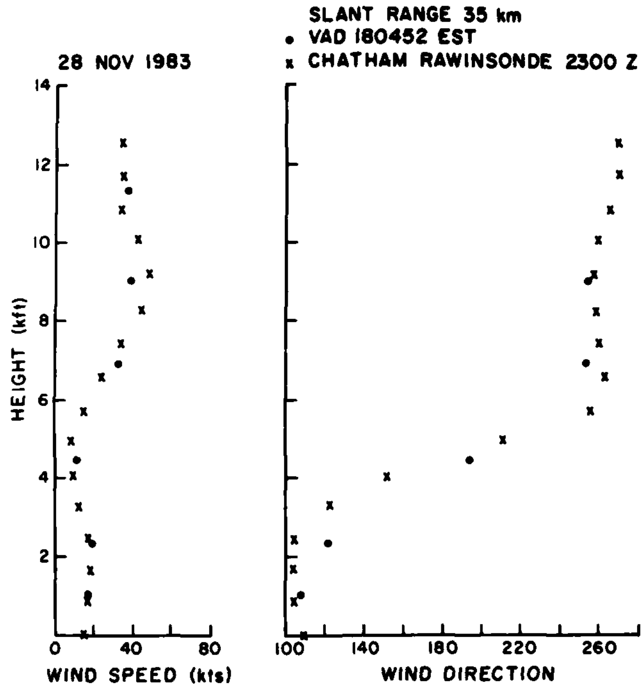

Figure 5. VAD and Rawinsonde Comparison, 28 November 1983

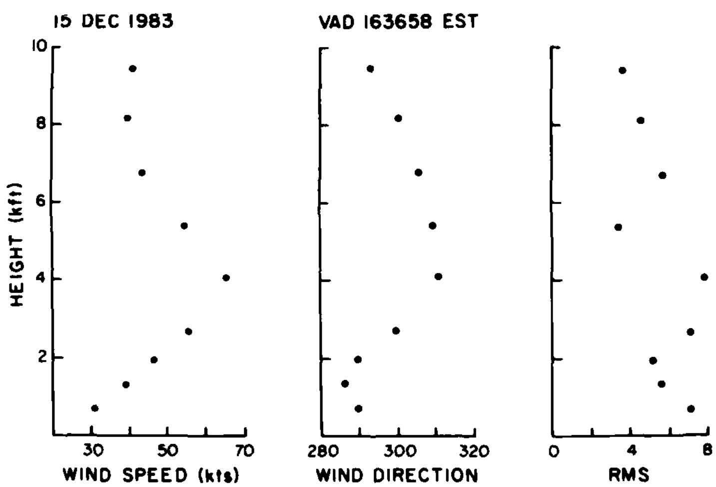

Figure 6. VAD Wind Profile on 15 December 1983

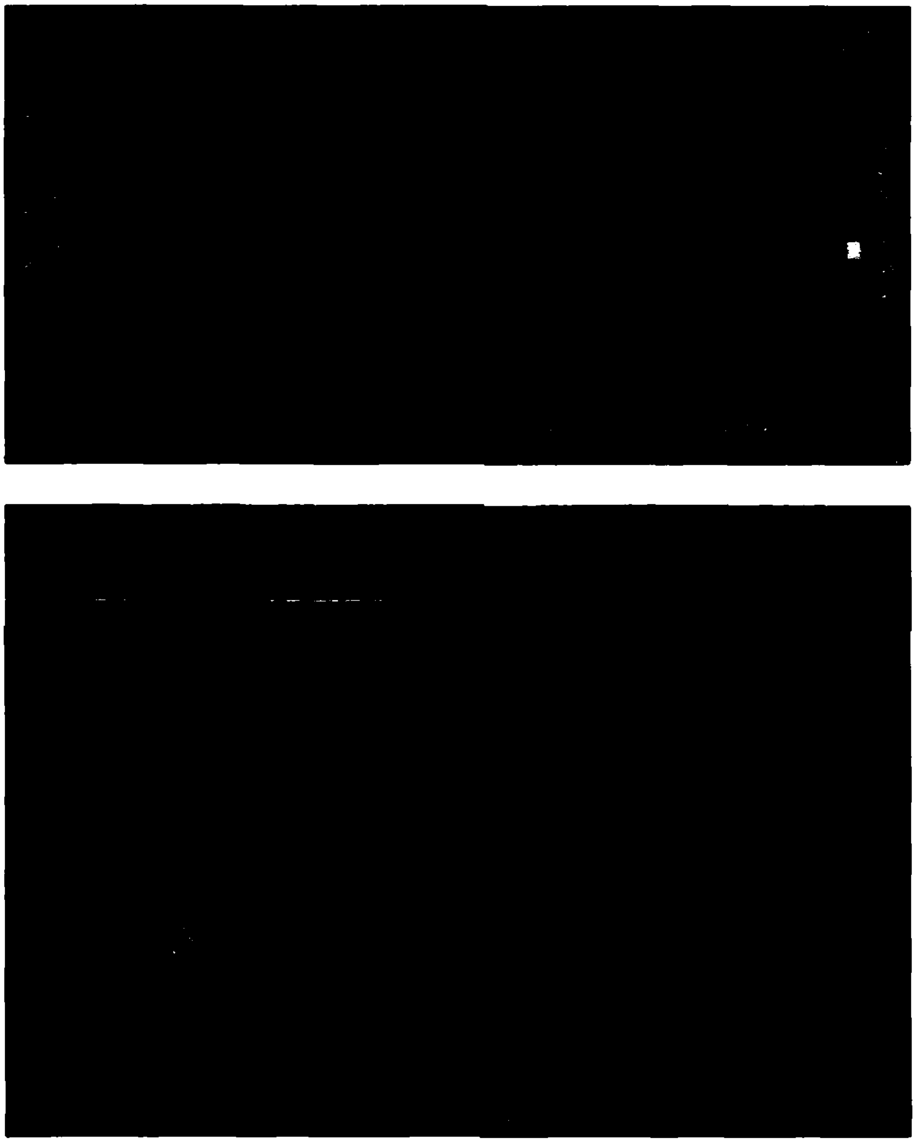

Figure 7. Examples of Base (lower) and Derived (upper) Wind Products Observed in Part I, 25 November 1983. Wind barbs are expressed in nautical miles per hour (knots). Note the low-level jet in velocity PPI image for 1442 EST as well as in the time height sections for the period approximately 1/2 hour before and after the PPI

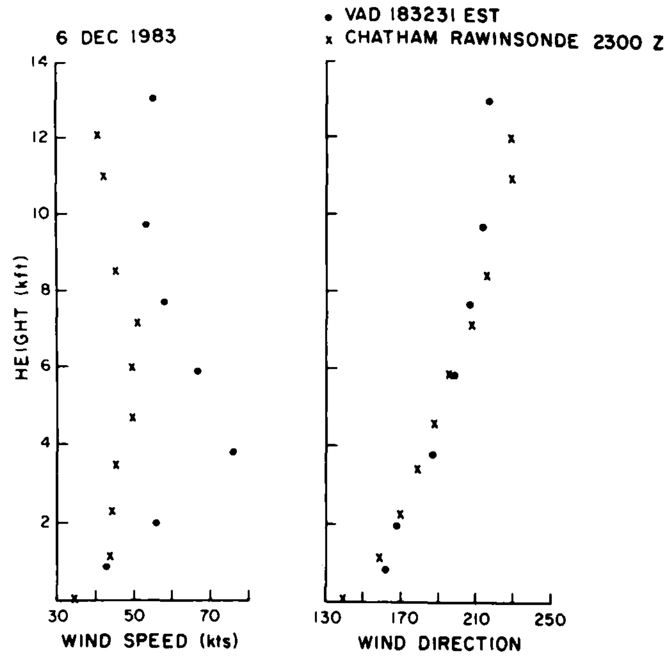

Figure 8. Comparison of VAD and Rawinsonde Data, 6 December 1983

When showers and thunderstorms occurred (as they did on 6 DEC), the MRASS reflectivity and velocity data processing produced the intermediate analysis files that contain additional information on the kinematic properties of the precipitation. By isolating the cellular structure of the threshold reflectivity selected (usually 25 or 30 dBZ) for three-dimensional analysis, the software produced the maximum reflectivity, the cell mass, and measured the signature strengths of hail, cyclonic shear, and centroid motion.

Summaries of the product files recorded on 10 days during November and December in BAND were plotted with similar data recorded during spring thunderstorms in Oklahoma. In Figure 10, the BAND data include a few values greater than 46 dBZ that occurred in thunderstorms embedded in a warm front overrunning ahead of a major winter cyclone. Otherwise, the median value of 35 dBZ and a peak value of about 48 dBZ ar consistent with winter rainfall measurements. The height of the bright band (melting level) is apparent in the height profile (Figure 11) which shows the maximum reflectivity in winter in Boston occurs at about 6000 ft. As expected, the severe thunderstorms in Oklahoma created a secondary peak at about 20,000 ft.

The comparison of storm mass (Figure 12) shows a difference of about a factor of 1.5. Although the more stratified winter storms are larger scale, their lower maximum reflectivities result in lower mass values.

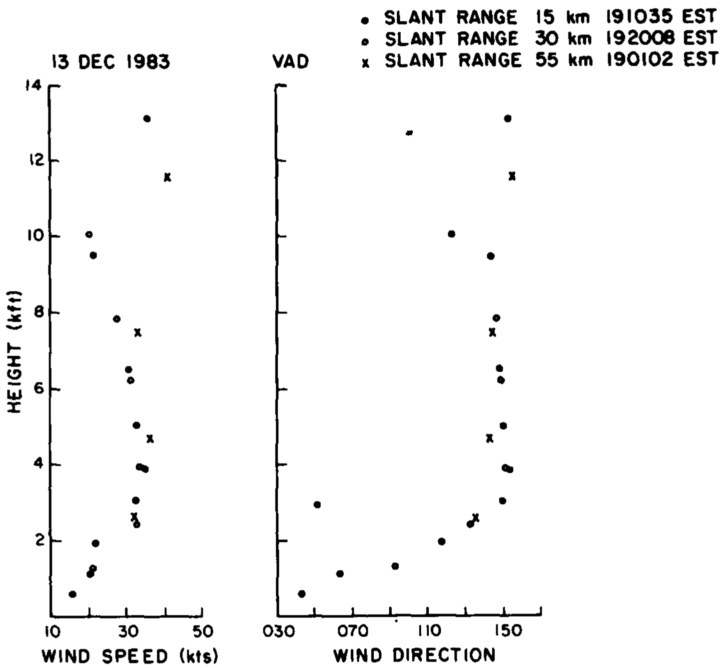

Figure 9. VAD Wind Profiles Made at Three Range Settings on 13 December 1983

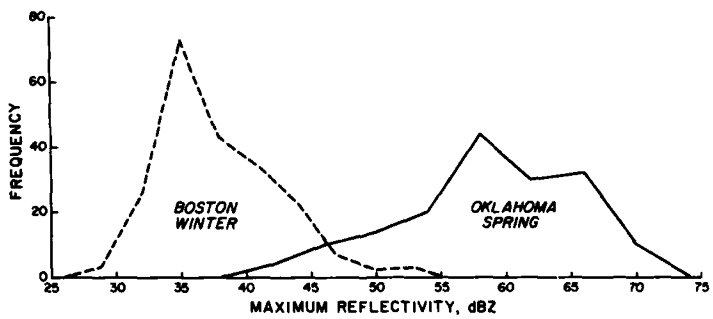

Figure 10. Comparison of Maximum Reflectivities Observed in Winter at Boston and in Spring at Oklahoma City

Although no severe thunderstorms occurred, operational experiences during Part I resulted in several improvements in both analysis and display software. Demonstration packages, using floppy disks, were prepared for use in training and orientation briefings at AFGWC and NSSFC. Numeric values of the wind velocities

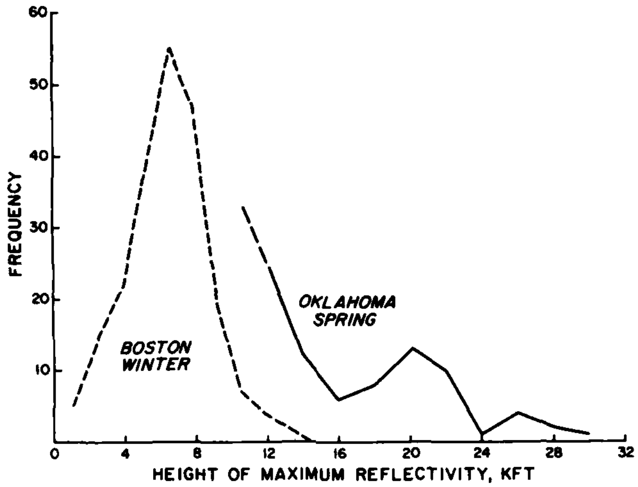

Figure 11. Comparison of the Heights of Maximum Reflectivities in Winter at Boston and in Spring at Oklahoma City

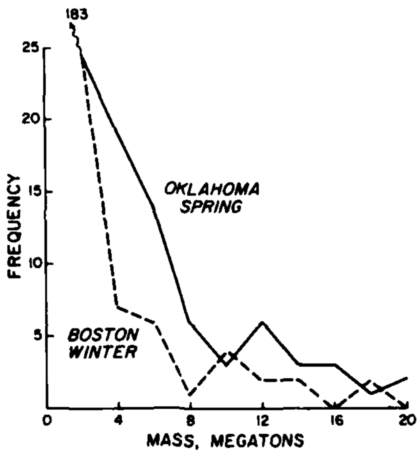

Figure 12. Comparison of Storm Mass in Winter at Boston and in Spring at Oklahoma City

were added to the time-height sections of wind profiles. Other changes involved averaging the reflectivity data to obtain the maximum reflectivity for a cell, combining the VAD analysis for simultaneous operation with storm tracking, and lowering the reflectivity threshold from 18 to 10 dBZ to process and display lighter precipitation.

Activities in Part I ended on 19 December 1983.

7.2 Part II, 10 January to 9 March

Operations in Part II began 10 January, just in time to observe a major winter snow storm (see Figure 13). Again, as in Part I, the VAD wind profiles were excellent, with sufficient signal to consistently analyze both the wind velocity and local divergence to a height of over 4 km (Figure 14. Similar storms occurred on 19 January and 30-31 January.

The storm of 30-31 January was analyzed in greater depth to illustrate the behavior of the wind profile data during the passage of a developing cyclone. The growth and movement of this cyclone was classical—starting near Cape Hatteras ahead of an advancing upper trough and moving northward along the coastal front to link with the vorticity maximum moving into New England from the west. These storms have been studied extensively; see, for example, Sanders and Gyakum,[7] Bosart,[8] and Marks and Austin.[9]

Radar operations on 30 January began at 1800 EST, when the storm was about 6 hours old and centered 400 km south, near Atlantic City, NJ (see Figure 15). Light snow began at the radar site shortly after 1900 EST. The cyclone moved very rapidly northward, and by 0100 EST on 31 January it was 100 km SE of Providence, RI. The surface temperature remained near 32° F with wet snow continuing most of the night. Approximately 4.5 in. of snow had accumulated at the radar site by 0500 EST. The developing coastal cyclone was then centered near Nantucket Island and moving toward Cape Cod. At Boston, the snow changed to rain and then back to snow. Total snow accumulation at the radar site was 7 inches. Boston received 3.6 inches. The 0700 EST surface synoptic patterns for 29-31 January and the 31 January 500 millibar chart, which are presented in Figure 15, show the intense coastal cyclone and upper level trough which combined to produce the heavy snowfall.

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7. Sanders, F., and Gyakum, J. R. (1980) Synoptic-dynamic climatology of the "bomb", Monthly Weather Review 108:1589-1606.
8. Bosart, L. F. (1981) The President's Day Snowstorm of 18-19 February 1979: A sub-synoptic scale event., Monthly Weather Review 109:1542-1566.
9. Marks, F. D., and Austin, P. M. (1979) Effects of the New England coastal front on the distribution of precipitation, Monthly Weather Review 107:53-67.

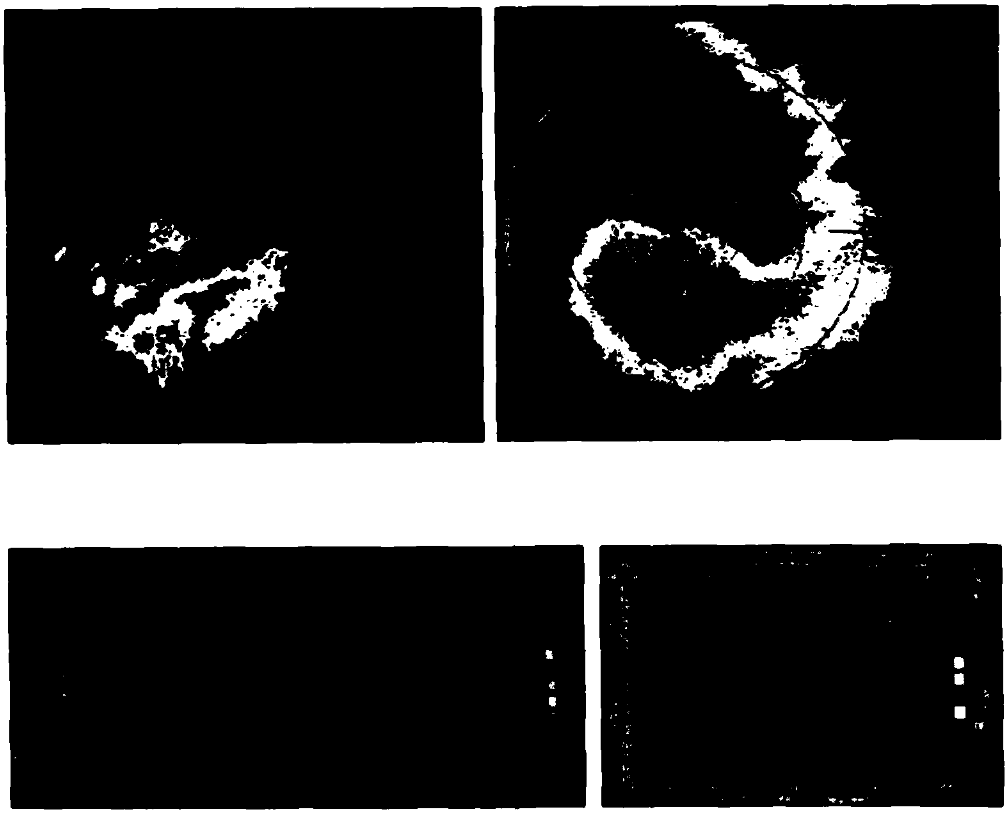


Figure 13. Base and Derived Products for the Snowstorm on 10-11 January 1984. Upper photographs show reflectivity and velocity PPI images. The sine wave best fit by the VAD algorithm is shown in the lower right. The lower left shows the time-height cross section of the wind velocities observed between 2217 EST and 0201 EST. Note the first observation (labeled 1900 S) is the NWS rawinsonde data recorded at Chatham, MA

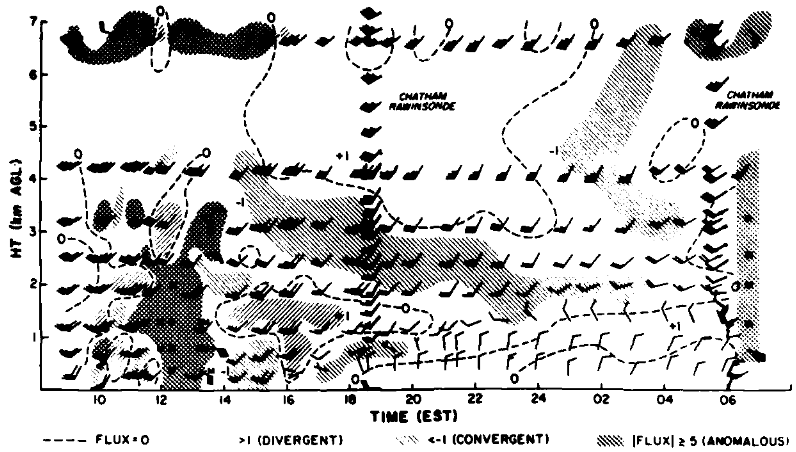


Figure 14. Time-Height Cross Section of Doppler Winds and Divergence for 10-11 January 1984

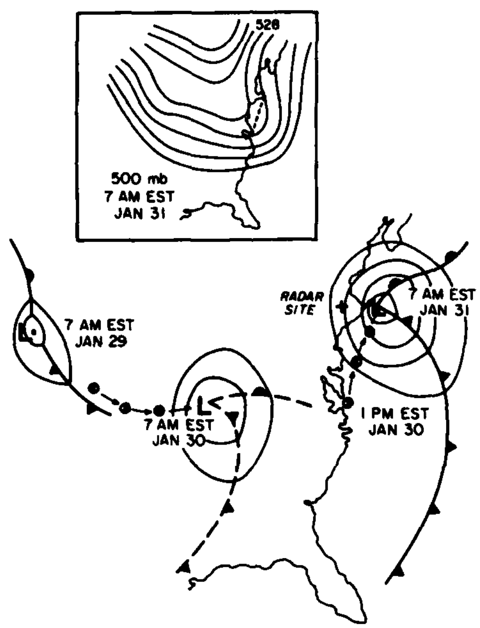
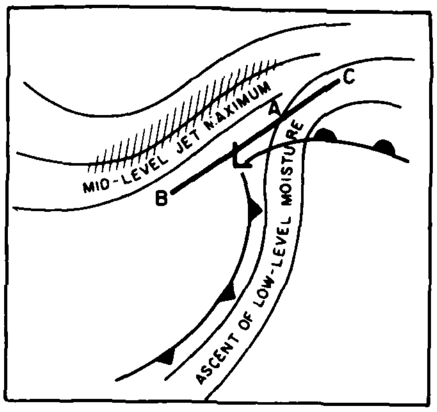


Figure 15. Surface and Upper-Air Patterns on 29-31 January 1984

Laborious but clever analysis by researchers of infrequent rawinsonde data have derived an empirical model of these cyclones which shows a narrow band of moist air flowing northward, moving parallel to the cold front and ascending from below the 900 mb level to the 500 mb level above the wave crest (see Figure 16). Such a band of moist air is believed to be responsible for the narrow zone of southeast winds shown in Figure 17 for the 0424 EST volume scan. In the time section shown in Figure 18, the low-level winds are seen to back ahead of the approaching warm front. By 0700 EST, the warm front is detectable at a height of 3.5 km.



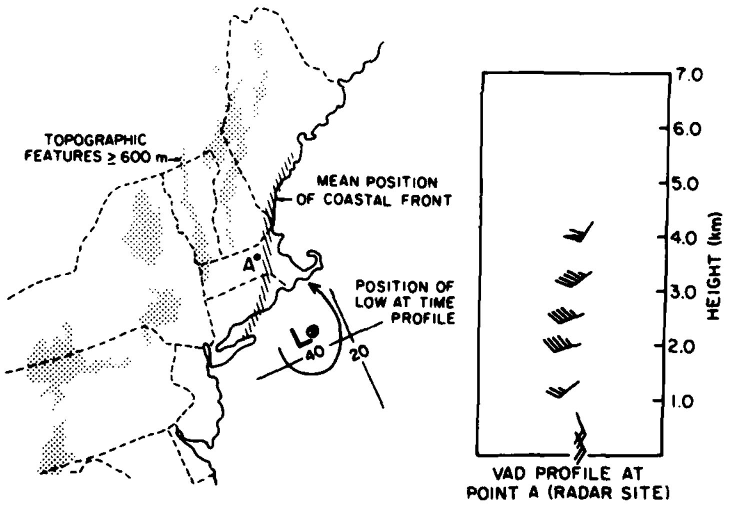


Figure 16. Cyclonic Model Described by Harrold[10] (top), that Matches Analysis of Doppler Winds Along Section BC (see Figures 17, 18 and 19) During the Approach and Passage of the Coastal Cyclone on 30-31 January

10. Harrold, T.W. (1973) Mechanisms influencing the distribution of precipitation within baroclinic disturbances, Quart. J. R. Meteor. Soc. 99:232-251.

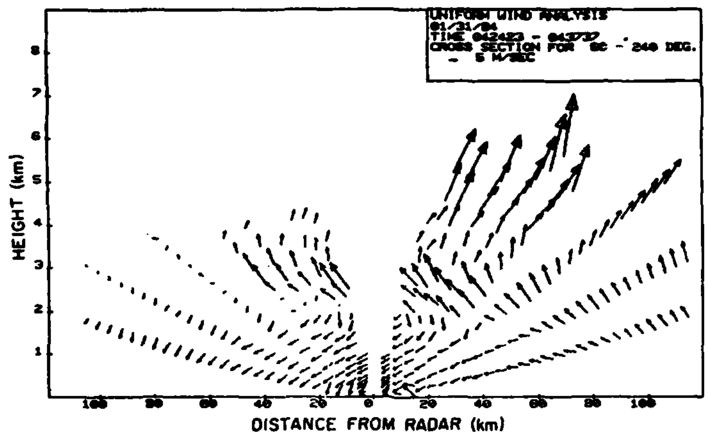


Figure 17. Vertical Cross Section of Wind Velocities Derived From the Uniform Wind Algorithm Along an Azimuth of 060 Degrees (right) to 240 Degrees (left) Using the 0424 EST Volume Scan. The narrow zone of southeast winds between 2 and 3 km altitude is believed to be the "conveyor belt" of moisture-laden air ascending ahead of the cold front

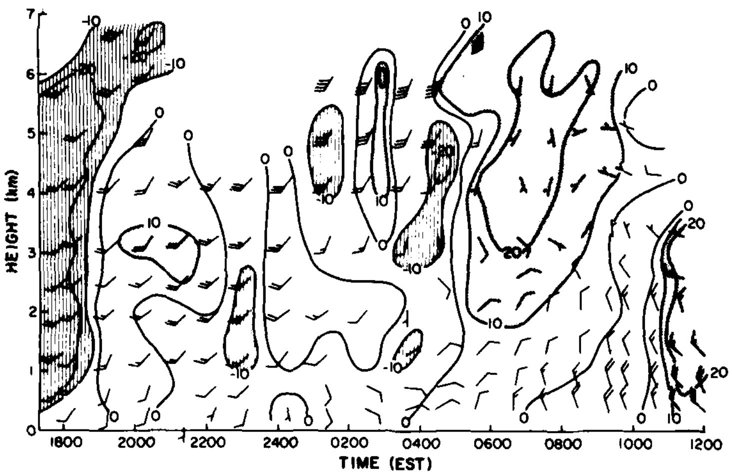


Figure 18. Time-Height Cross Section of Doppler Derived Winds and Vertical Velocities for 30-31 January 1984 Shows the Strong Influx of North Winds at the Low Levels as the Cyclone Approached Massachusetts. Winds aloft turn southerly and weaken as the upper-level trough axis approaches. A narrow band of moisture-laden southeasterly flow is noticeable just above the boundary layer from 0344 to 0743 EST. Stippled areas are upward motion; striped areas are downward

Using the measured cyclone speed of 36 km hr^{-1} (derived from the 6-hr surface positions), the time section was converted to a space section (Figure 19), to better illustrate the transitions in the air mass regimes. The most important transitions were: (1) the steady backing of the boundary layer wind from southeast to northeast between 0100 and 0500 EST; (2) the arrival of the "conveyer belt" (see Harrold[10]) of moisture-laden air from the southeast; (3) the juxtaposition of the mid-level jet maximum bringing the potentially cold de-stabilizing air to mix with the ascending moisture-laden air; and (4) the veering in the post frontal flow, which advected in much colder air and changed the rain to snow at Boston after 0500 EST. Examples of the precipitation and radial velocity patterns are shown in Figures 20 and 21 respectively for 0320 EST, when the coastal cyclone was passing closest to the radar site.

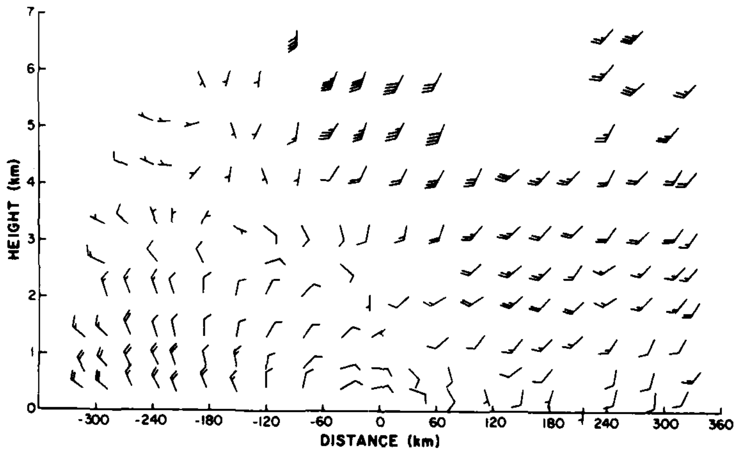


Figure 19. Space Cross Section of Wind Profiles Transposed From 1800 EST, 30 January to 1200 EST, 31 January, Derived Winds Using a Storm Motion of 36 km hr^{-1} From 230 Degrees. Zero distance corresponds to 0300 EST, 31 January. Wind barb speeds are in m/sec

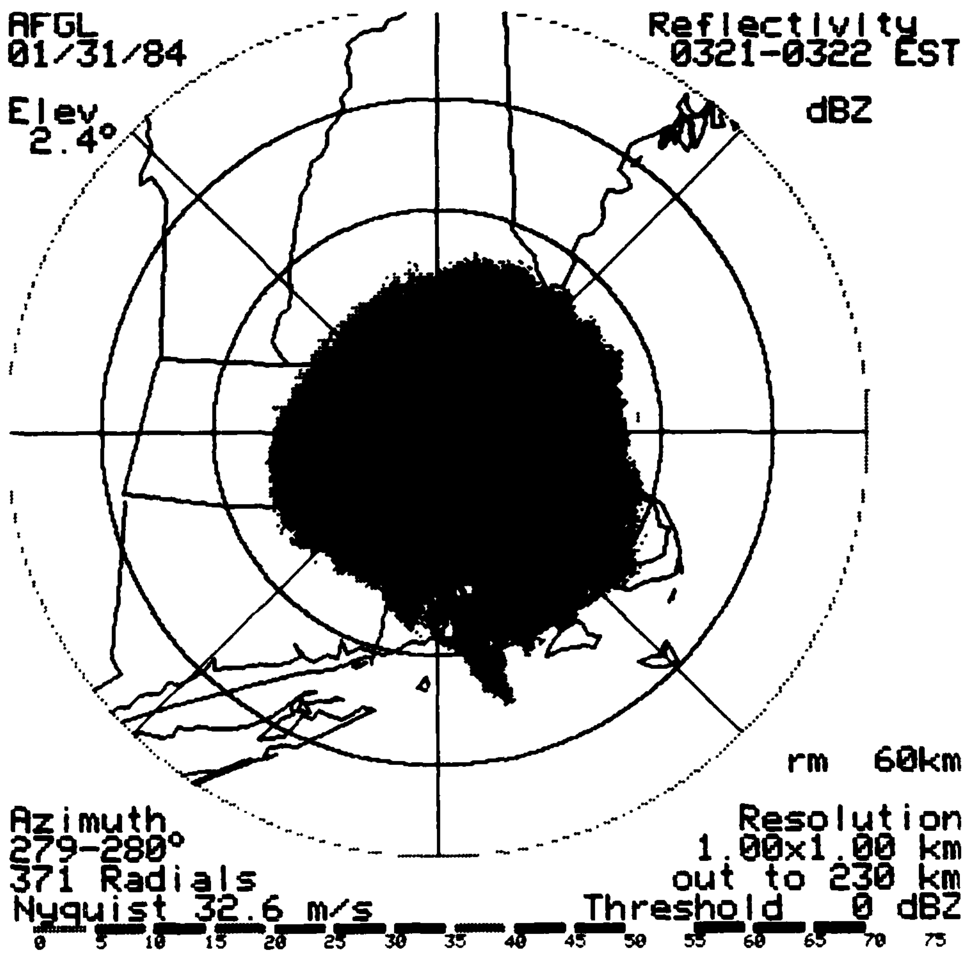


Figure 20. Reflectivity Base Product at 0321 EST, 31 January, When the Coastal Cyclone Was Passing Closest to the Radar Site. Range markers are spaced 60 km apart. Reflectivity contours (in dBZ) are defined by the color bars along lower edge

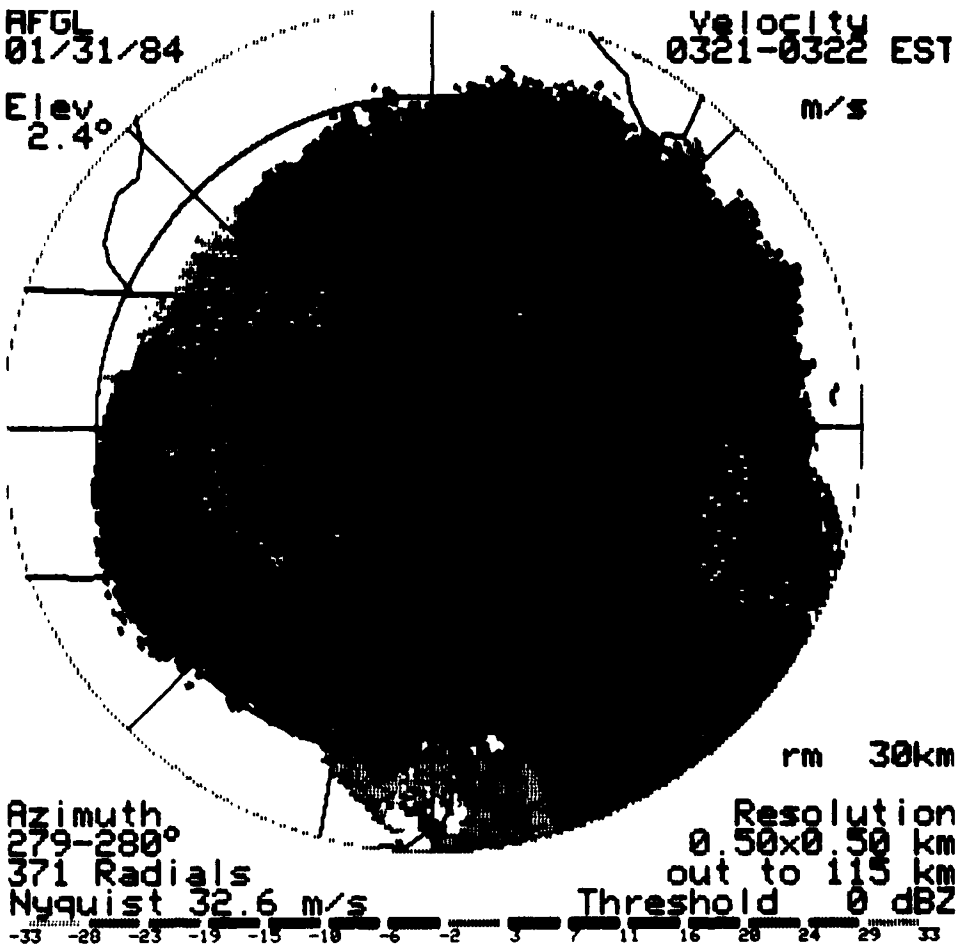


Figure 21. Velocity Base Product for 0321 EST, 31 January. Range markers are spaced 30 km apart. Velocity contours, in m/sec, are defined by the color code along lower edge. Note the complex zero radial velocity pattern associated with the reversal of the wind direction above the boundary layer

Forecasters at the Boston WSFO believe this type of analysis from NEXRAD systems will be extremely beneficial in anticipating changes in airport winds and in advising the public of developing traffic hazards (as rain changes to freezing rain or snow).

Similar storms with commensurate VAD data occurred several more times in February. In some cases, two VAD wind profiles (east and west of the radar) were obtainable. In other cases, there were not sufficient data to separate and only the full-scan profile could be attained. Several of the wind profiles showed the development of low-level jets.

7.3 Part III, 2 May to 28 June

Although the winter storms observed in Part I and Part II were of considerable interest, the principal objective of the Boston demonstration was to verify the performance of the severe storm algorithms in the northeastern United States. Data recorded from severe thunderstorms on four days during Part III are used here to illustrate both the similarities and the differences in severe thunderstorms we observed in Oklahoma and Massachusetts.

On many severe thunderstorm days in the U.S. the air mass characteristics are similar, and regardless of geographical location the storms are isolated supercells with similar shapes, reflectivity profiles, and cyclonically swirling updrafts. As an illustration of this similarity, several of the composite hazards products recorded on 13 June 1984 in Massachusetts are shown with products recorded in Oklahoma on 13 May 1983. Synoptic surface and upper-air patterns on both days (Figure 22) were not indicative of severe weather development, although a severe thunderstorm watch area was issued in Oklahoma soon after the radar detected the formation of the first storm.

Severe thunderstorms that occurred in Massachusetts on 7 June 1984, and on 23 May and 26 May 1984, were quite different from those on 13 June. The storms on 7 June also were not associated with a front or squall line. However, the air mass was substantially cooler with a more northerly flow (Figure 23). This type of severe storm is seen occasionally in Oklahoma but it is much more common in the northern half of the U.S. in the early spring.

The comparison of the storms on 13 June in Massachusetts with those on 13 May in Oklahoma illustrated the performance of the algorithms in alerting weather centers to the need for a severe thunderstorm watch and then in alerting the WFSO forecaster to issue a severe thunderstorm warning. The composite hazard displays shown in Figures 24 and 25 are at the times that watches should be in effect. In both cases, the trends show the initial intensification. The next displays (Figures 26 and 27) show the two storms a short time later when severe thunderstorm warnings should have been issued. Surface reports of hail and wind damage confirmed these diagnoses. Figures 28 and 29 show the further development and movement of the Massachusetts storms as the thunderstorm complex matured (at 1700 EST) and then later as it began to dissipate (at 1800 EST). The similarities (and differences) of the storm characteristics from the two regimes are indicated in Table 3. More detailed information on the Oklahoma storms is given in the report on the Oklahoma City demonstration.[4]

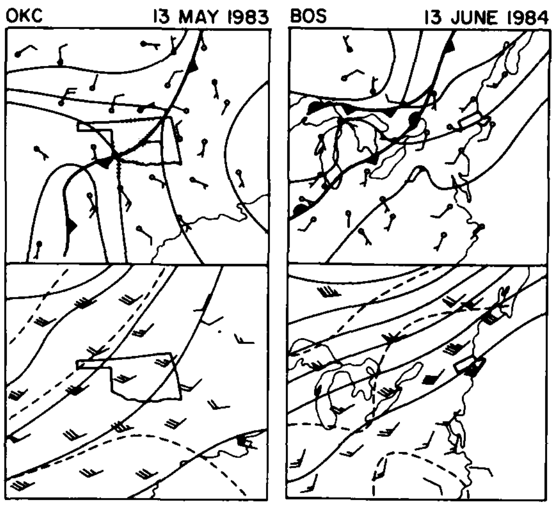


Figure 22. Surface and Upper-Air Patterns on 13 May 1983 and 13 June 1984

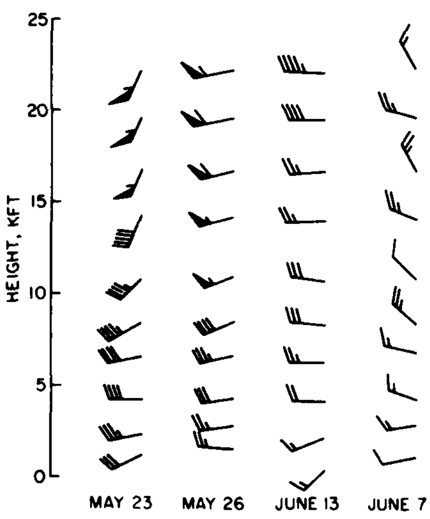


Figure 23. VAD Derived Wind Profiles on Four Severe Thunderstorm Days in Massachusetts

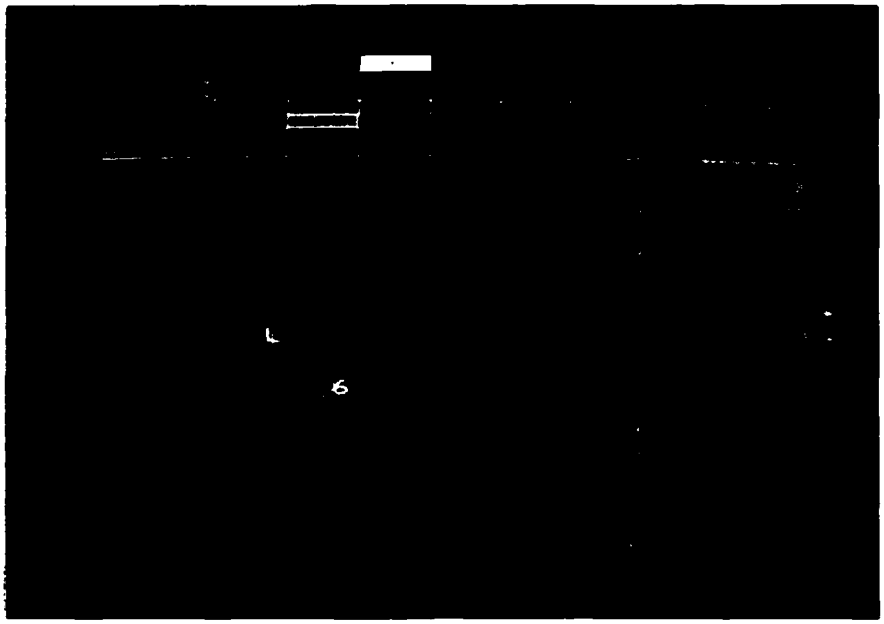


Figure 24. Composite Hazards on 13 May 1983, at 1510

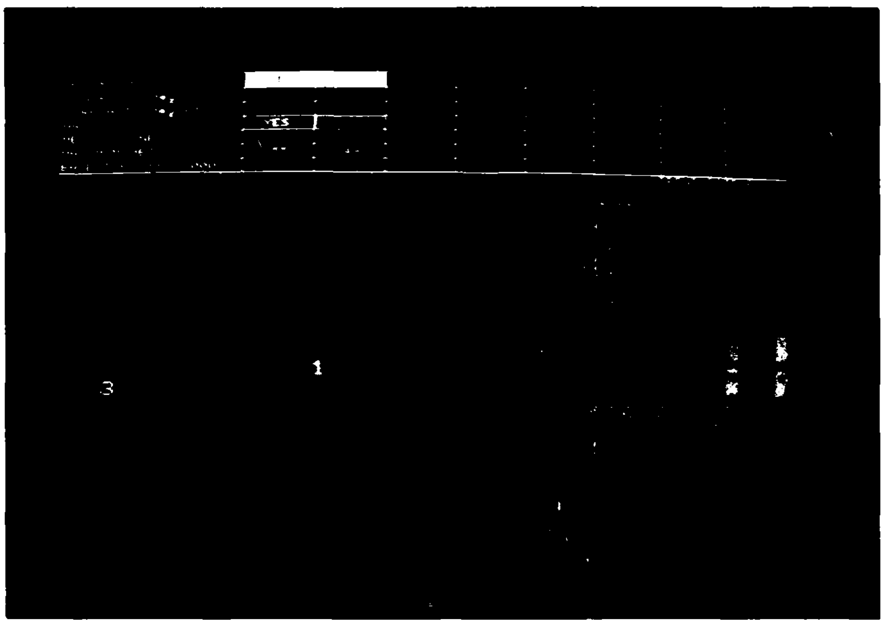


Figure 25. Composite Hazards on 13 June 1984, at 1510

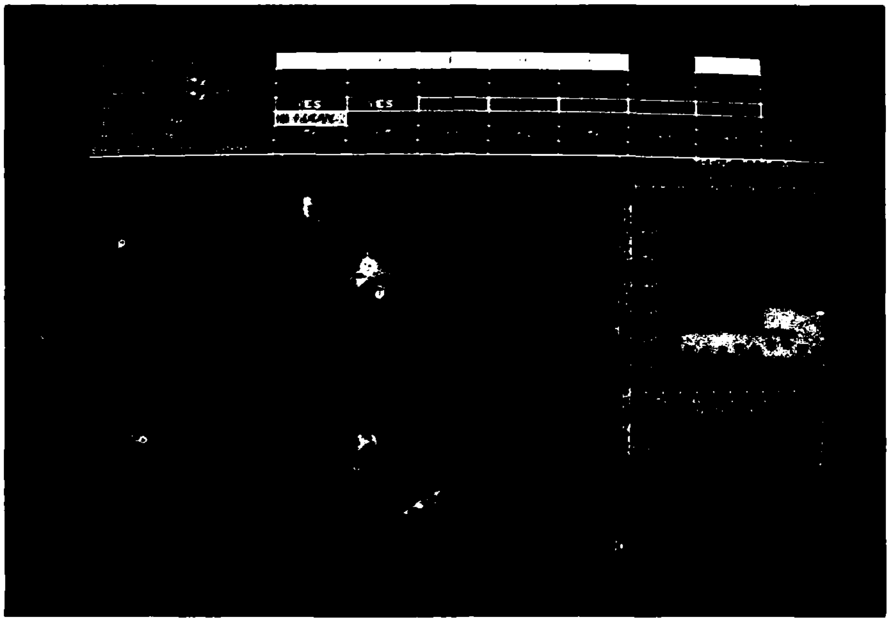


Figure 26. Composite Hazards on 13 May 1984, at 1530

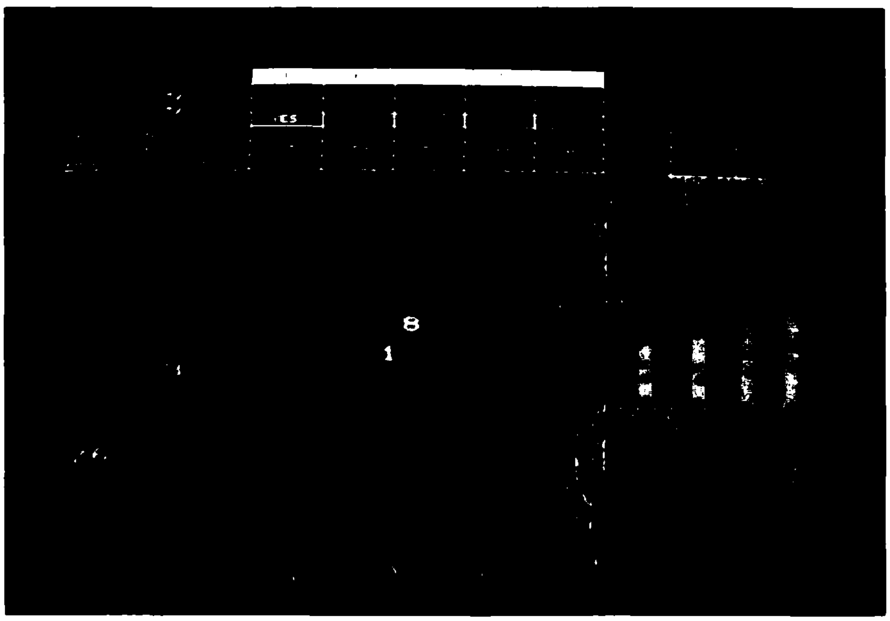


Figure 27. Composite Hazards on 13 June 1984, at 1530

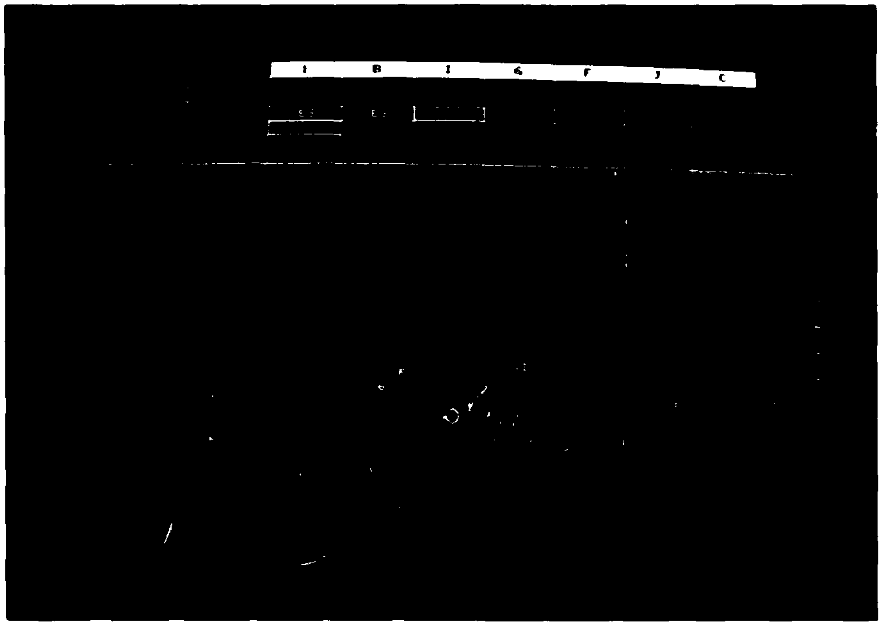


Figure 28. Composite Hazards on 13 June 1984, at 1700

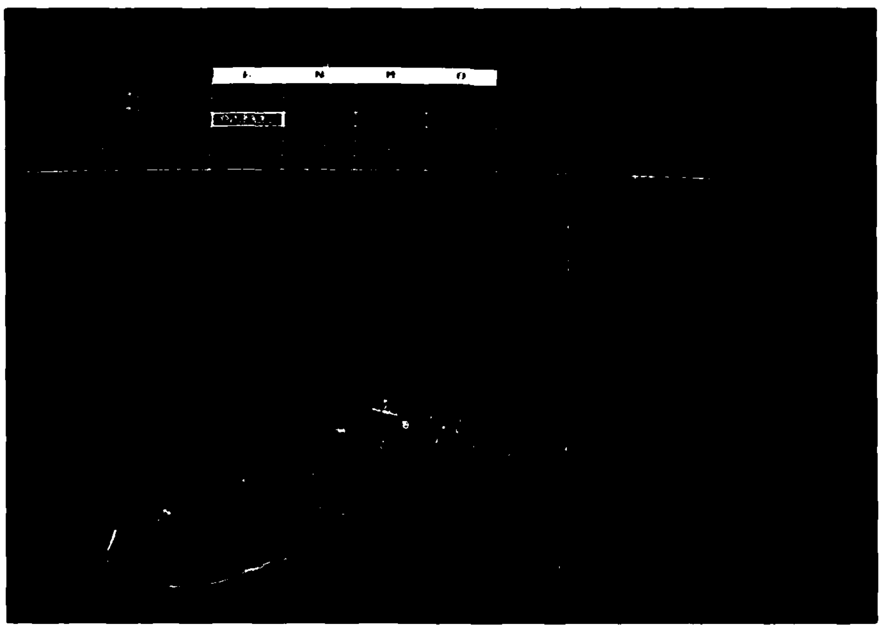


Figure 29. Composite Hazards on 13 June 1984, at 1800

Table 3. Average Characteristics of Five Storms

	13 May 1983 (1520 CST) Oklahoma	13 June 1984 (1525 EST) Massachusetts
Maximum Reflectivity	58.4 ± 6.0 dBZ	54.0 ± 7.8 dBZ
Height of Maximum Reflectivity	5.14 ± 2.66 km	3.72 ± 2.5 km
Diameter of 30 dBZ	22.8 ± 6.2 km	11.72 ± 7.0 km
Hail Score	44.2 ± 22.5	29.4 ± 38
Movement:		
Direction	216 ± 34 deg	297 (2 storms)
Velocity	14.6 ± 4.0	14.5 ms^{-1}
Cyclonic Shear	$2.9 \times 10^{-3} \pm 1.23\ s^{-1}$	$3.2 \times 10^{-3}\ s^{-1}$

The storms on 7 June started to develop at 1200 EST. The radar measurements show these thunderstorms were unusually small with very intense cores that developed rapidly (and collapsed just as suddenly). The collapse was often accompanied by new growth nearby, but downwind—as if a new cell was triggered by the outflow. The structure files indicated the diameters of the (30 dBZ) cores were characteristically less than half the diameters of super cells, yet the maximum reflectivities often exceeded 60 dBZ. Furthermore, the increase from 30 dBZ to 60 dBZ frequently occurred in less than the 14 min between volume scans. Even with the 5-min volume scans proposed for NEXRAD, automatic alerts will be needed to catch this new development in sufficient time to issue warnings.

Storm structure analysis and storm tracking were also affected adversely by the small core sizes. Default limits set for the horizontal displacement of slice centroids and the matching of consecutive cell positions must be reset when cell diameters are expected to be less than about 4 km. On 7 June, the first severe storm reported by the public (Figure 30, labeled 'X' in the Attributes Table and graphic display) developed at 1538 EST. By 1634 EST (Figure 31) the maximum reflectivity was 67 dBZ and severe weather (hail and damaging wind) was occurring at Ayer, MA, located at 335 degrees, 19 km from the radar.

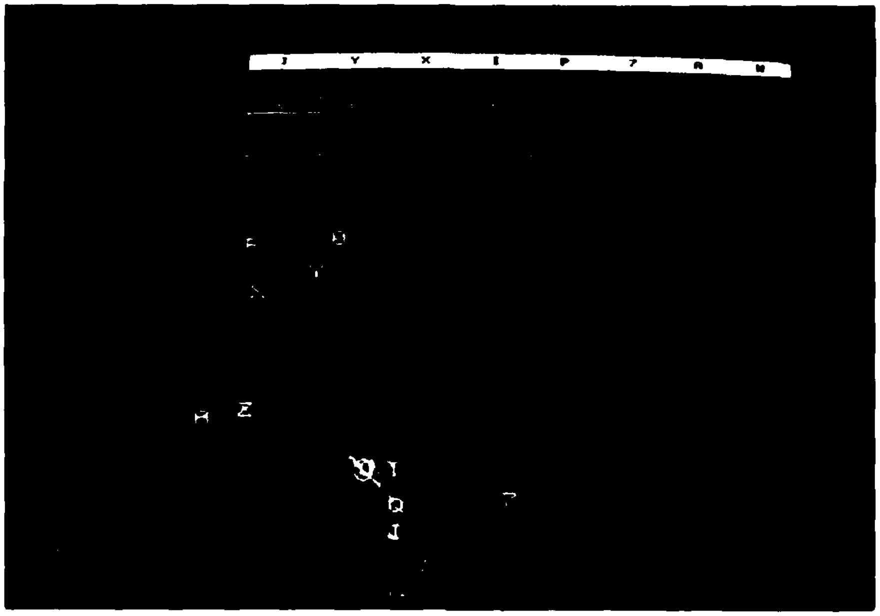


Figure 30. Composite Hazards on 7 June 1984, at 1538

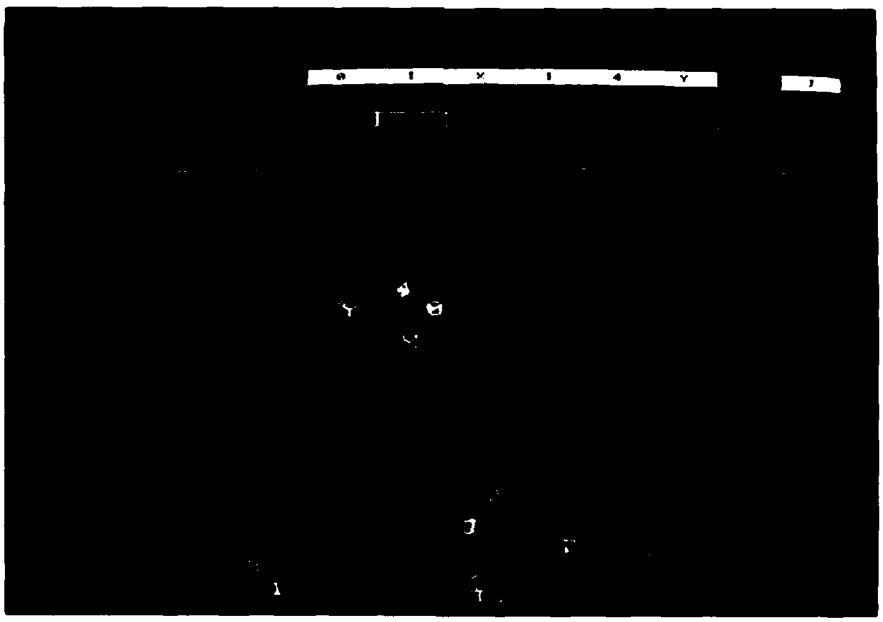


Figure 31. Composite Hazards on 7 June 1984, at 1634

At 1634 EST, the track of this storm shows a sudden "jump" eastward. Close inspection of the structure files shows a new cell developed and was assigned the same identification number. Post analysis of this problem has led to changes in both the centroid and tracking algorithms. The centroid logic is being changed to assure the vertical assignment of the slice centroids to the proper storm. At the present time, the centroid algorithm fails to assign a slice centroid properly whenever it is located beyond the radius of the cell slice at the preceding elevation scan. The solution now under test at IOTF is to examine the overlap of the slices in adjacent scans and associate the slices to the same storm whenever a sufficient (pre-designated) overlap is measured, regardless of the horizontal distance between centroids. A second centroid matching problem occurred when the lowest level scan contained fragmented 30 dBZ cores, although the higher scans contained only one area. At the present time, the algorithm assigns the fragment with the largest mass as the component of the three-dimensional centroid and the other low-level fragments are renamed as new cells, even though they are descending from the same precipitation mass aloft. The solution now under test is to group these fragments into one slice centroid for compositing with centroids from the higher scans.

A change is being made to the tracking algorithm to improve the matching of storms in adjacent volume scans. At the present time, the storms are ranked by mass in each volume scan and then matched by comparing their current locations to locations of mass-ranked storms in the previous volume scan. The test locates the largest previous storm's location that falls within a distance specified by an expected maximum velocity of 2 km min^{-1}. This logic is being changed to allow the test to proceed through the mass-ranked list of all candidates, in order to select the one which best matches the past track history of the previous storms. Also, matches will not be allowed if unreasonable tracks (that is, reversals or turns greater than ± 45 degrees) are encountered.

The last two severe weather days reviewed here occurred three days apart in May. The 0700 surface and upper-air analyses on both 23 May (Figure 32) and 26 May (Figure 33) showed cold fronts approaching New England with about equal potential for the continuing development of a line of showers and thunderstorms. Note the analysis on 26 May indicated the thunderstorms were on a squall line ahead of the front. Table 4 shows the radar characteristics shortly after 1600 EST on both days. The similarities of the cell measurements are striking to say the least. The average range (of the largest 12 cells) is identical, and reflectivity maxima and the heights of the reflectivity maxima are only slightly different. The cell movement on both days was southwest, 13 to 16 m s^{-1}. The average heights of the 30 dBZ contours and the heights of the reflectivity maxima were very similar. The greatest difference was in the average radial velocity component, which was 5 m s^{-1} higher on 23 May, in agreement with the stronger 850 mb flow.

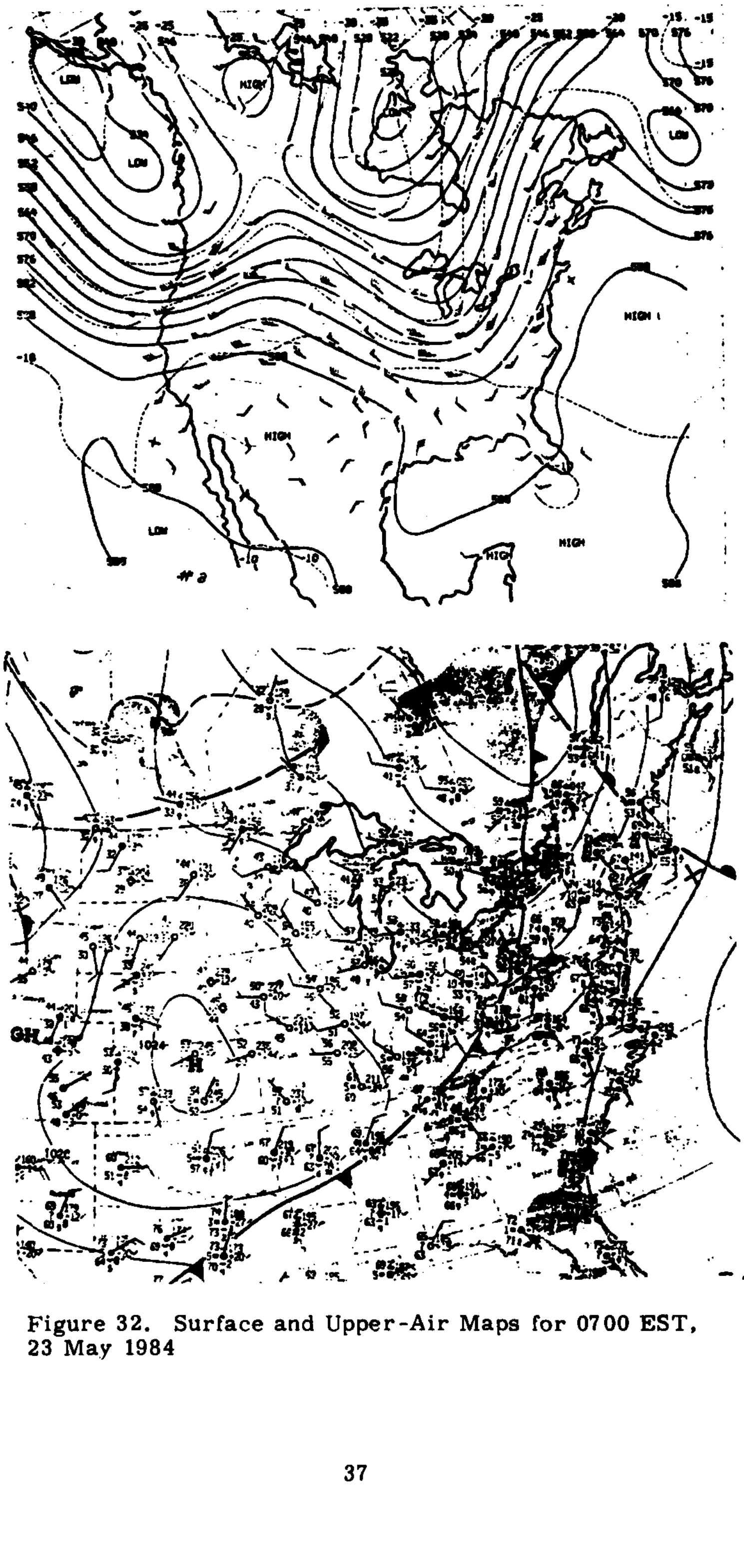


Figure 32. Surface and Upper-Air Maps for 0700 EST, 23 May 1984

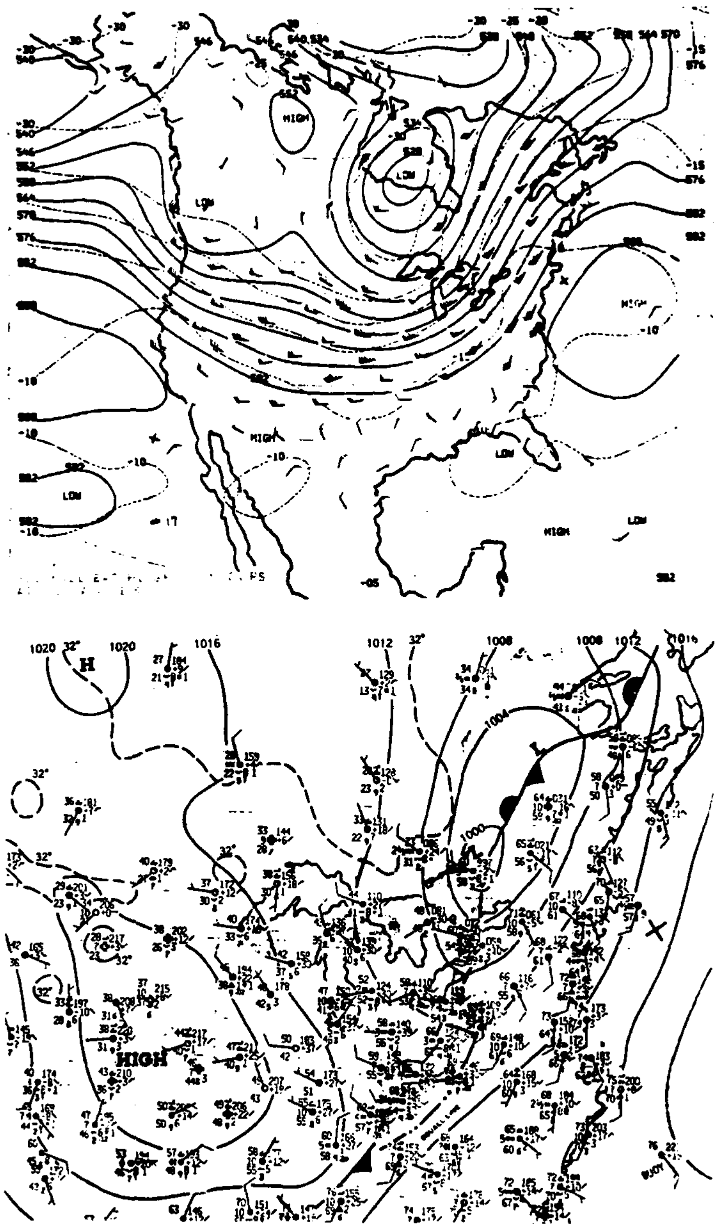


Figure 33. Surface and Upper-Air Maps for 0700 EST, 26 May 1984

Table 4. Comparison of Average Characteristics of Twelve Largest Thunderstorms on 23 May and 26 May 1984, at 1609 EST

	23 May (cold front)	26 May (squall line)
Range	136.5 km	136.5 km
Height (30 dBZ)	4.2 km	4.2 km
Height Maximum Z_e	3.3 km	2.8 km
Maximum Z_e	45 dBZ_e	47 dBZ_e
Diameter (30 dBZ)	13 km	7 km
Motion:		
Direction	233 deg	229 deg
Speed	16 ms^{-1}	13 ms^{-1}
Average Maximum Radial Velocity at Lowest Elevation	-23 ms^{-1}	-18 ms^{-1}

By 1700 EST (Figures 34 and 35), both lines had progressed eastward to central Massachusetts. The storms on 23 May intensified to greater than 55 dBZ briefly, but then decreased to average about 50 dBZ as they continued to cross central and eastern Massachusetts. Several reports of hail and damaging wind had been received from eastern New York and extreme western Massachusetts in early afternoon; however, reports of only heavy rain and gusty winds were received the remainder of the day.

In contrast, the storms on 26 May intensified to over 60 dBZ and produced strong hail signatures and a mesocyclone. As on 23 May, few if any reports of damage were received. However, the radar signatures were much stronger on 26 May and therefore the potential (and number of warnings) should have been greater.

8. CONCLUSIONS AND RECOMMENDATIONS

We suggest staff at the Boston WSFO review warning criteria with public safety officials to determine if the NEXRAD criteria for severe weather should be raised. We believe the signatures found during Part III were valid hazards to transportation—including aircraft and automobile passenger safety.

The energies of most storms observed in Massachusetts are expected to be lower than Oklahoma storms because of their smaller size. Very localized, damaging winds probably do occur in many east coast thunderstorms, but the likelihood of their causing significant property damage is not very great. If those storms had occurred over more open terrain, we believe the damage might have been greater. Of course, exceptions do occur—the Ayer storm on 7 June is an excellent example of the need for such warnings—in rather small but intense storms.

The Boston area demonstration met its principal objectives in addition, accomplished the following specific tasks:

(1) The NEXRAD algorithms were exercised in a wide variety of seasonal weather, judged typical of the northeastern U.S. Over 200 hours of excellent data were archived for future study of algorithm performance and new product evaluation. It is recommended that IOTF and AFGL edit and select 10 percent of these data for use by the NEXRAD contractors in test and evaluation of NEXRAD performance.

(2) The NEXRAD-like products produced and distributed during Part I showed the need for high vertical resolution and sector partitioning of the wind profiles. The demonstration proved such data will be very useful at Base Weather Stations, NWS Forecast Offices, and Air Traffic Control Centers.

It is recommended that the NEXRAD wind profiling algorithms be modified to use more than a single range gate to increase the height resolution; to normalize the rms measurements according to S/N; and to provide wind speed, wind direction, and normalized rms values to an initial resolution of 500 ft (from 500 ft to 1500 ft), 1000 ft (from 1000 ft to 10,000 ft) and 2,000 ft (10,000 ft to 20,000 ft). The maximum range used in wind profiling should not exceed 40 km.

(3) Post analysis of the winter storm data recorded during Part II demonstrated the usefulness of the time and space sections of the wind profiles to help delineate the air mass and frontal structure of the wind in major winter storms. Tests of the NSSL VVP algorithm suggest it should be used to generate a new cross-section product like that illustrated in this report (see Appendix B).

(4) Review of the severe storm data and related products distributed during Part III show similar performance of the algorithms in Oklahoma and Massachusetts when the thunderstorms are large and isolated. Post analysis of smaller storms and storms contained in fronts and squall lines show the centroid and tracking algorithms need modifications to improve the linking of the slice centroids and to improve the matching of the storms between volume scans.

(5) The processing and distribution of the intermediate files from the severe storm algorithms appears to be a viable substitute for manually constructed radar reports. The files were used to construct "strawman" product displays at the national centers which adequately summarized storm intensity, location, track, and hail signatures.

It is recommended that the users review plans for periodic summaries of NEXRAD velocity and reflectivity products to be distributed automatically to the national weather forecast centers.

(6) The performance of the mesocyclone algorithm used during BAND was inadequate. The algorithm failed to threshold signatures properly to meet the warning requirements of either Oklahoma City or Boston WSFO's. This result was not surprising, since the algorithm was undergoing revision during these tests. Two versions of the mesocyclone algorithm currently exist and both versions are being tested by the IOTF. In addition, solutions to the thresholding problem are being examined to ensure that the algorithm will meet the tri-agency warning requirements.

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Appendix A

User Responses to NEXRAD-like Products

BAND USER'S QUESTIONNAIRE - PART A

DATE: ____________________

I. General Design

1. What do you feel are the most serious shortcomings of the present radar displays in your facility?

Slow data retrieval; limited access to radars; no RHI (2); poor tornado detection; range limits; poor calibration; no range control of remoted data; no range control; hard to see; slow, limited data; memory tube PPI; too much downtime; none; dial up to non-dedicated lines; colors change.

2. What characteristics of these displays do you feel should be retained in NEXRAD?

VIP levels (3); reflectivity info; zoom; reflectivity contours (6); reflectivity levels; PPI display and method of getting tops; everything but memory tube; all (2).

3. Do you feel qualified in quantitative interpretation of your present displays?

Yes (9); No (1)

4. How do you feel about interactive control of radar displays versus automatic sequential output of products?

Auto with manual override (4); none (1); interactive with auto option (1); interactive only (5); interactive better (2); both (3); OK (1); interactive important (1).

BAND USER'S QUESTIONNAIRE - PART B

DATE: ______________________

Please indicate if you have any color blindness. ___Yes _17_No

1. Which of these best describe your work in connection with this demonstration? (You may check more than one category.)

   _4_ Lead Forecaster _8_ Forecaster _3_ Administrator

   _3_ Other (Please Specify) CWSU Met _4_

---

1. Do you like the concept of using numerical entries to select:

   a) Overlay Features? _7_Yes _3_No _1_Not Sure

   b) Map Options? _7_Yes _3_No _2_Not Sure

2. How easy are the numerical entries to use?

   _1_Very Easy _9_Easy _2_Difficult ___Very Difficult

3. Are the programs that use the numerical entries easy to understand?

   _11_Yes ___No

4. a) How useful is the state scale presentation?

   _4_Very Useful _12_Useful ___Not Very Useful

   b) Which two state scales are most useful? (Indicate your first and second choices with 1 and 2 respectively)

PEASE	BOSTON	
	___	Scale Size 0 (largest area)
1	2	Scale Size 1 (second largest area)
3	1	Scale Size 2 (third largest area)
	___	Scale Size 3 (fourth largest area)
2	3	Scale Size 4 (smallest area)

5. Is the labelling on the overlays useful? 14 Yes 3 No

6. Should we include the range mark overlay feature?

14 Yes 3 No

7. In the Attribute Table, what information should be retained?

15 Centroid 17 Cell Motion

17 Hail Indication 16 Mesocyclone Indication

16 Maximum dBZ 17 Base/Top

8. a) Do you need three levels of reflectivity displayed?

17 Yes 1 No

b) Is the format suitable? 18 Yes ___ No

9. a) If you could change the number of levels, how many should there be? ___ 6 (7); 5 (3); 4 (2)

b) What values should they have? ___

DVIP Levels (7); 10,20,35,50,60; 10,20,30,40,50; 15,25,35,40+

10. Are the cell's centroids easily identified in the graphic window? 8 Yes 10 No

Are the cell tracks easy to see? 12 Yes 5 No 1 Sometimes

Was the mesocyclone "symbol" appropriate? 14 Yes 3 No 2 Too Big

Was the "HAIL" message clear? 17 Yes ___ No 1 Sometimes

11. Overall, how would you rate the format of this product?

5 Excellent 2 Good 2 Fair ___ Poor

12. Are there any changes that should be made to the housekeeping portion of this product? 3 Yes 12 No

If yes, what should they be?

Need area tracker; base/top data unclear; indicate latest wind update; allow user to send longer message.

13. Please rate the following display characteristics:

Choice of Colors: 10 Excellent 7 Good 1 Fair ___ Poor

Character Size: 6 Excellent 7 Good 2 Fair 2 Poor

Color Brightness: 10 Excellent 6 Good 2 Fair ___ Poor

Line Thickness: 8 Excellent 6 Good 2 Fair 2 Poor

14. Did you use the trend product at any time during this demonstration period? 16 Yes 2 No

15. If yes, how would you characterize your use of this product during this demonstration period when:

a) Severe storms were occurring?

10 Routinely* 4 Occasionally* 2 Seldom*

1 No severe storms occurred

b) Non-severe storms were occurring?

10 Routinely 4 Occasionally 2 Seldom

1 No storms occurred

c) Other? (Please explain the weather conditions present.)

1 Routinely 4 Occasionally 1 Seldom

7 Only used this product when storms were occurring

*"Routinely" means that several times during a shift, when suitable weather is occuring, the product was viewed for its meteorological information even if no action was taken; "occasionally" implies at least once during a shift; and "seldom" implies a few times during the demonstration period.

16. How useful are the trends of the following features:

a) Base and top of 30 dBZ echo

_1_ Very Useful   _11_ Useful   _2_ Not Very Useful

b) Height of centroid

_5_ Very Useful   _6_ Useful   _4_ Not Very Useful

c) Height of maximum dBZ

_8_ Very Useful   _4_ Useful   _2_ Not Very Useful

d) Flash-flood index

___ Very Useful   _4_ Useful   _8_ Not Very Useful

17. In the Trend Product, what information should be retained?

_11_ Base and top of 30 dBZ echo
(Threshold at which tracking starts)

_11_ Height of maximum reflectivity

_12_ Maximum reflectivity value

_5_ Flash-flood index

18. Do you prefer (check one):

_12_ to have the PPI reflectivity format displayed along with the trend information from a single storm, or

_2_ to see the trends from several storms instead of the PPI?

19. Data from up to 12 past times are currently saved for the Trend Products. In general is that:

_10_ about the right amount of data   _4_ too much data

___ Not enough data

20. Please rate the following display characteristics:

Choice of Colors: 6 Excellent 9 Good ___Fair ___Poor

Axis Legibility: 7 Excellent 8 Good ___Fair ___Poor

Bar Size: 7 Excellent 8 Good ___Fair ___Poor

Legibility of characters on bars: 6 Excellent 7 Good 2 Fair ___Poor

21. Overall, how would you rate the usefulness of this product?

5 Excellent 9 Good 1 Fair ___Poor

22. Did you use the wind profile products at any time during this demonstration period? 15 Yes ___No

23. If yes, how would you characterize your use of this product?

4 Routinely 13 Occasionally 1 Seldom

24. Please indicate how useful you found each of the four graphs in this product.

a) Speed Profile

8 Very Useful 10 Useful ___Not Very Useful

b) Direction Profile

9 Very Useful 9 Useful ___Not Very Useful

c) Runway Component Profile

___Very Useful 10 Useful 8 Not Very Useful

d) RMS Error Profile

1 Very Useful 6 Useful 11 Not Very Useful

25. Which portions of this products should be retained?

18 Speed Profile 8 Runway Component Profile

18 Direction Profile 5 RMS Error Profile

26. **In what other ways would you like to see this data presented?** Dots connected; numerical format; no colors; need just a few good winds; numerical format; allow 2 soundings to be shown.

27. **Please rate the following characteristics of this product?**

Choice of Colors:	8 **Excellent**	9 **Good**	1 **Fair**	___ **Poor**
Axis Legibility:	7 **Excellent**	9 **Good**	1 **Fair**	___ **Poor**
Line Thickness:	9 **Excellent**	8 **Good**	1 **Fair**	___ **Poor**
Brightness:	10 **Excellent**	7 **Good**	1 **Fair**	___ **Poor**
Format:	6 **Excellent**	10 **Good**	2 **Fair**	___ **Poor**

28. **Overall, how would you rate the usefulness of this product?**

___ **Excellent** 7 **Good** 10 **Fair** 1 **Poor**

29. **a) How useful is the wind barb graph?**

11 **Very Useful** 5 **Useful** 1 **Not Very Useful**

b) Head wind/tail wind graph?

3 **Very Useful** 9 **Useful** 5 **Not Very Useful**

30. **Do you prefer the wind barb format, or would you prefer a numerical format (e.g., 270/20 meaning a wind of 20 kts from 270 degrees)?**

15 **Wind Barb Format** 2 **Numerical Format**

31. **Would you rather have a numerical format for the component graph?** 2 **Yes** 13 **No**

32. **What other ways would you like to see this kind of data presented?**

Addition of sounding temp data; only lowest few hundred feet is needed; also numerical format.

33. Please rate the following characteristics of this product.

Choice of Colors:	11 Excellent	4 Good	1 Fair	1 Poor
Brightness:	9 Excellent	7 Good	1 Fair	___ Poor
Axis Legibility:	9 Excellent	7 Good	___ Fair	1 Poor
Line Thickness	8 Excellent	8 Good	1 Fair	___ Poor
Format:	8 Excellent	7 Good	1 Fair	1 Poor

34. Overall, how would you rate the usefulness of this product?

7 Excellent   8 Good   ___ Fair   2 Poor

35. Did you use the Quality Control (Q) product during this demonstration period?

8 Yes   9 No

36. If yes, how would you characterize your use of this product during this demonstration period?

___ Routinely   5 Occasionally   5 Seldom   1 Never

37. Did you call this product before or after viewing one of the other VAD products?

2 Before   3 After   3 Before and After

38. Please rate the following characteristics of this product.

Choice of Colors:	4 Excellent	4 Good	1 Fair	___ Poor
Axis Legibility:	4 Excellent	4 Good	1 Fair	___ Poor
Line Thickness:	4 Excellent	4 Good	1 Fair	___ Poor
Brightness:	5 Excellent	3 Good	1 Fair	___ Poor
Format:	4 Excellent	2 Good	2 Fair	1 Poor

39. Overall, how would rate the usefulness of this product?

1 Excellent   5 Good   1 Fair   2 Poor

3-D Product

xx. Did you use the 3-D product at any time during this demonstration period? __3__ Yes __1__ No

xx. If yes, how would you characterize your use of this product during this demonstration period when:

a) Severe storms were occuring?
__2__ Routinely __1__ Occasionally ____ Seldom
____ No severe storms occured

b) Non-severe storms were occuring?
____ Routinely __3__ Occasionally ____ Seldom
__1__ No storms occured

c) Other? (Please explain the weather conditions present.)

____ Routinely __2__ Occasionally ____ Seldom
____ Only used this product when storms were occuring

xx. How useful are the following features of the 3-D cross-section:

a). 2D center of mass for each level
__1__ Very useful __2__ Useful __1__ Not very useful

b). Height labels at each level
__2__ Very useful __2__ Useful ____ Not very useful

xx. Should the dimensions of the 2D grids be labeled? __3__ Yes __1__ No

xx. In the 3-D product, what information should be retained?

__3__ Position(s) of 2D center(s) of mass
__4__ Height labels at each level
__2__ Time at each level of the various tilts

xx. Do you prefer (check one):

a) ____To have the PPI BAND format with a reflectivity map displayed along with the 3-D product, or

b) ____To have a larger size 3-D product displayed only, or

c) __3__To have several 3-D cross-sections displayed at the same time, with a small insert of the PPI reflectivity also displayed, or

d) ____To have several 3-D cross-sections displayed at the same time, without the PPI reflectivity displayed

xx. On items a) and c) of xx., should the PPI reflectivity display also show the location of the 3-D product grid or cross-section?

__3__Yes __1__No

xx. Should there be an indication on the display when the reflectivity levels extend above and/or below the vertically stacked grids?

__4__Yes ____No

xx. If yes, should this be indicated on the display by (check one):

__2__An arrow
__2__A message
____Other (specify)

xx. Please rate the following display characteristics:

Choice of colors:	__3__Excellent	__1__Good	____Fair	____Poor
Brightness:	__1__Excellent	__3__Good	____Fair	____Poor
2D grid size:	__1__Excellent	__1__Good	__1__Fair	__1__Poor
Legibility of Characters:	____Excellent	__3__Good	__1__Fair	____Poor

xx. Overall, how would you rate the usefulness of this product?

__1__Excellent __3__Good ____Fair ____Poor

Appendix B

Doppler Report (DOPREP) Files

The routine dissemination of all NEXRAD information to the thousands of users currently receiving weather radar reflectivity summaries will require either a very significant improvement in communication capability or a commensurate compression of NEXRAD products. While conducting the operation demonstration at Boston, IOTF staff experimented with the construction and dissemination of intermediate files which allow distant users to select and plot both reflectivity and velocity products as needed.

During June 1984, intermediate analysis files from the VAD and severe weather algorithms were transmitted to the National Severe Storms Forecast Center and Air Force Global Weather Central. These files contained the derived wind profile information, three-dimensional storm structure information (including location, size, shape, and intensity for each storm at each elevation angle), forecasted movements of the storms, results of the hail and mesocyclone algorithms, and confidence factors for the algorithm results, along with basic header information (date, time, station ID, status, and operating parameters). The files were generated automatically, transmitted after each volume scan, and stored on disk at the centers. The center forecasters were then able to build products locally using the stored data sets and IOTF-developed display software, which included an extensive set of "Help" files also stored locally.

This prototype Doppler Radar Report (DOPREP) offered significant advantages over the current NWS operational radar report, including automatic file generation, frequent update potential, more detailed storm information, and the inclusion of Doppler derived wind information.

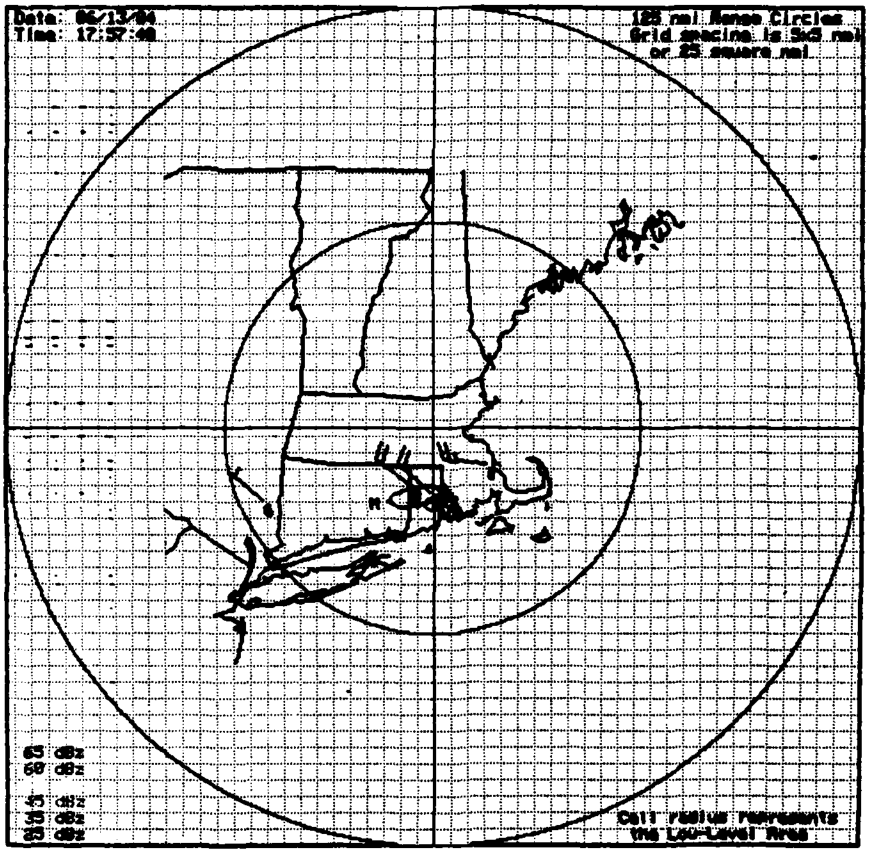

Figure B1. Graphic Plot of Storm Algorithm Package for Entire Volume Scan for 1757 EST, 13 June 1984, Shows Position of Storm Centroids, Size and Shape of Their 30 dBZ Contours, and Forecast Motion. Positive hail or mesocyclone identification causes the storm outline to blink on screen. All background maps, range rings, and grids are generated locally at user's request. Optional displays against this background include the choice of the storm component shape, size, and location for any selected elevation.

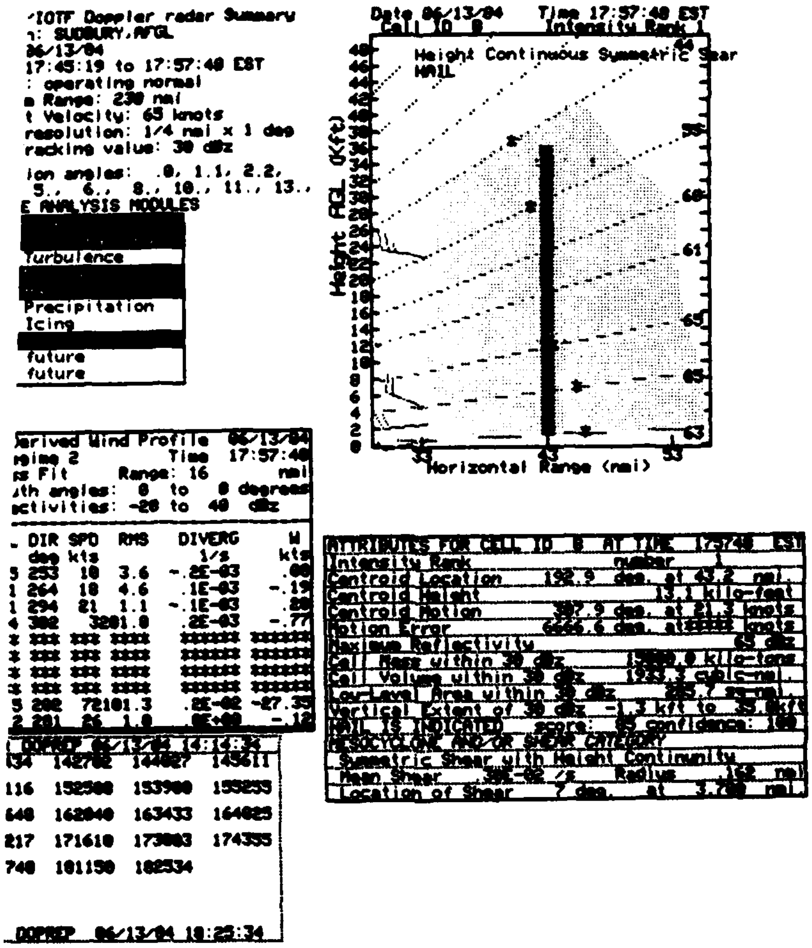

Figure B2. Header Information (upper near right) Contains Station Identification, Date and Time, as Well as Hardware Status, Operating Parameters, and Algorithm Status. Cell plot (upper far right) for Storm "B" uses storm structure and centroid information to simulate a storm cross section. Positive severe storm algorithm results are printed above the storm, and concurrent derived winds are plotted just to the left. A table of derived wind profile data (center near right) includes derived divergence and vertical velocities. A table of storm attributes (lower far right) contains the detailed output from the storm package for a selected storm. Observation times (lower near right) show that the local disk is storing 19 data sets running from 1414 EST to 1825 EST on 13 June. The local user has the option of looking at any stored data for any time. Locally generated graphic loops can also be generated

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