STATUS OF FAA TERMINAL DOPPLER WEATHER RADAR PROGRAMS

MARK W. MERRITT

MIT LINCOLN LABORATORY

23 OCTOBER 1987

N88-17632

- PROGRAM STATUS/SCHEDULES
    - MICROBURST/GUST FRONT PHENOMENOLOGY AND DATA
    - MEMPHIS (TN)/HUNTSVILLE (AL)
    - DENVER (CO)
- MICROBURST DETECTION ALGORITHM STATUS
- 1988 TEST PLANS

FAA GOALS FOR TDWR PERFORMANCE

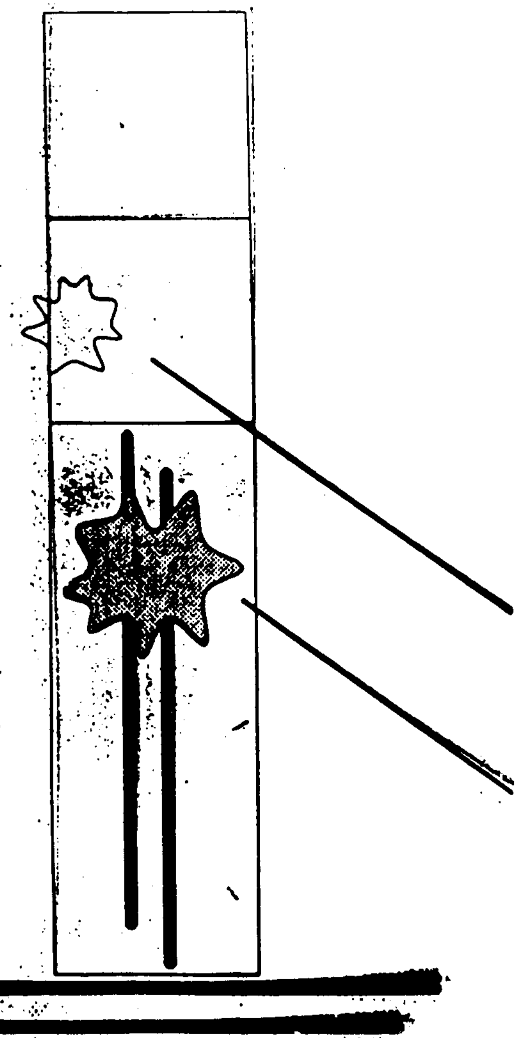
MICROBURST

- > 90% PROBABILITY OF DETECTION
- < 10% PROBABILITY OF FALSE ALARM
- ONE MINUTE ADVANCE WARNING
- ± 5 KNOTS (OR 20%) ACCURACY ON STRENGTH

GUST FRONT

- 20 MINUTE ADVANCE WARNING
- VERY LOW FALSE ALARM RATE

MICROBURST DETECTION OUTPUT PRODUCTS



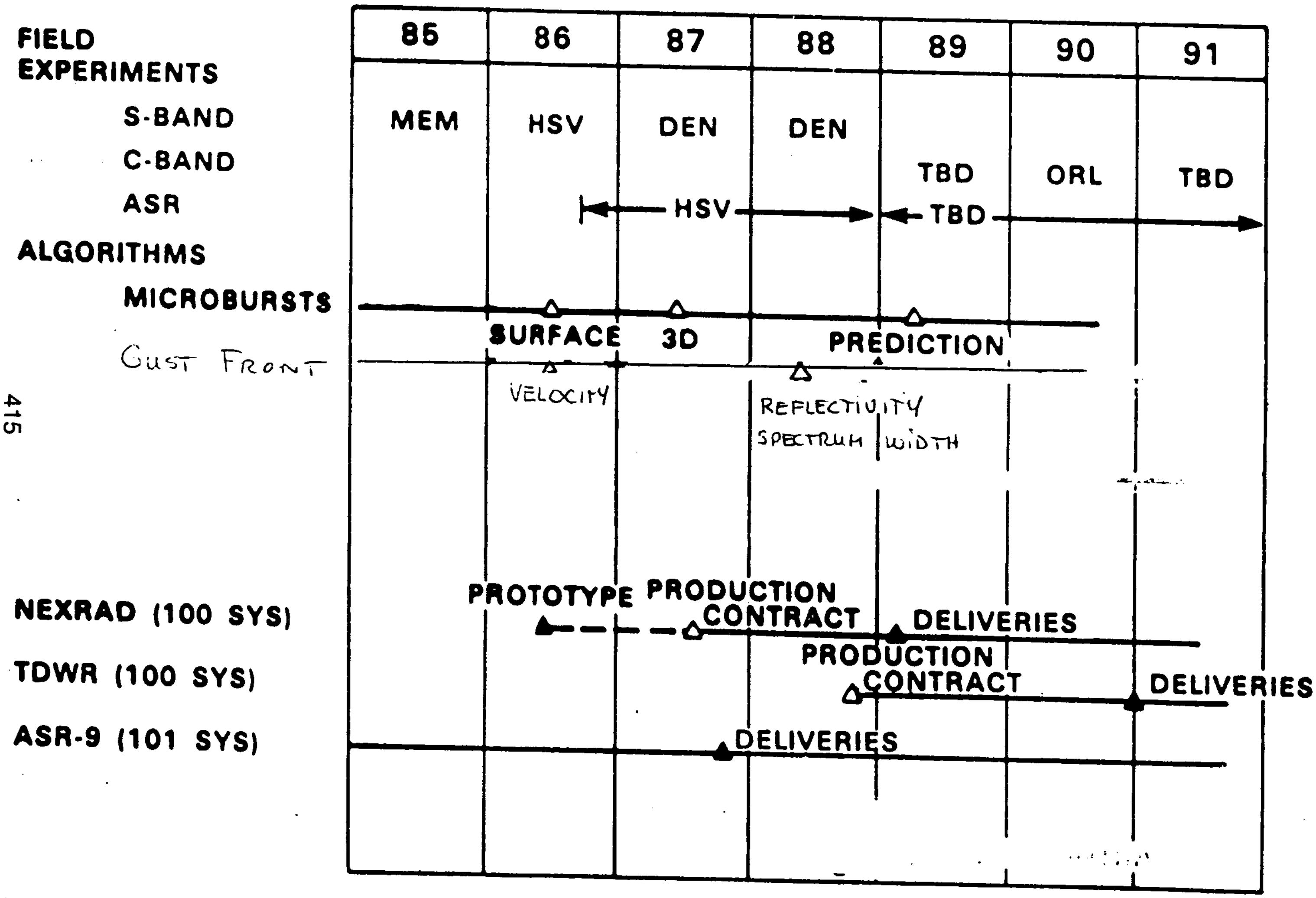
IDENTIFICATION
QUANTIFICATION
LOCATION
TREND

'MICROBURST, 15 KNOT LOSS,
1 MILE FINAL, INCREASING'

'MICROBURST, 30 KNOT LOSS,
ON THE RUNWAY, DECREASING'

desired output for users.

LINCOLN WEATHER RADAR PROGRAMS



88077-2

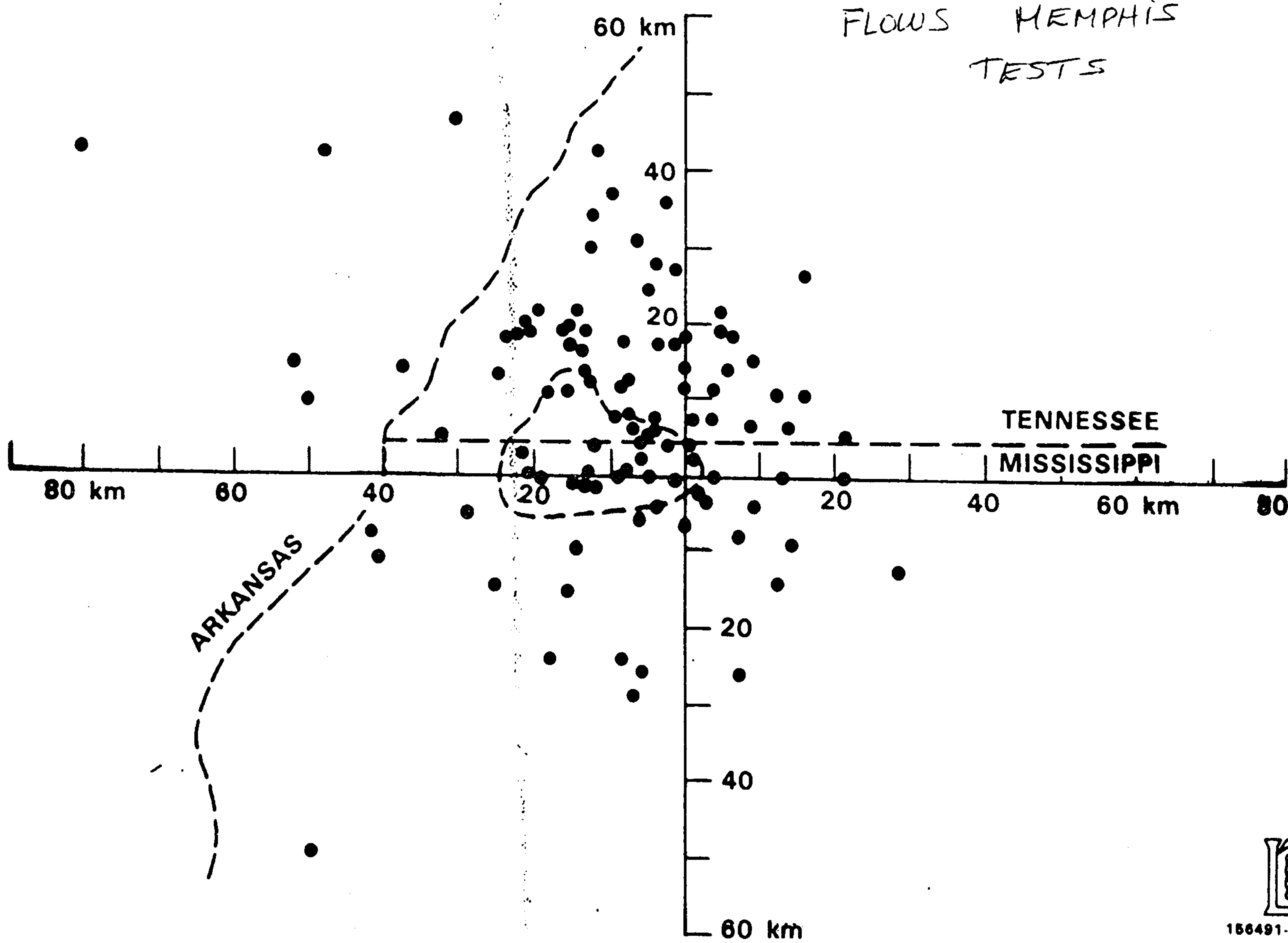
DOPPLER WEATHER RADAR PROGRAM MAJOR ELEMENTS

- TESTBED RADARS FOR DATA ACQUISITION AND FEASIBILITY DEMONSTRATION
- EXECUTION OF MAJOR MEASUREMENT AND PRODUCT DEMONSTRATION PROGRAMS IN VARIOUS REGIONS
- ANALYSIS OF DATA AND DEVELOPMENT OF HAZARD DETECTION ALGORITHMS

77365-4

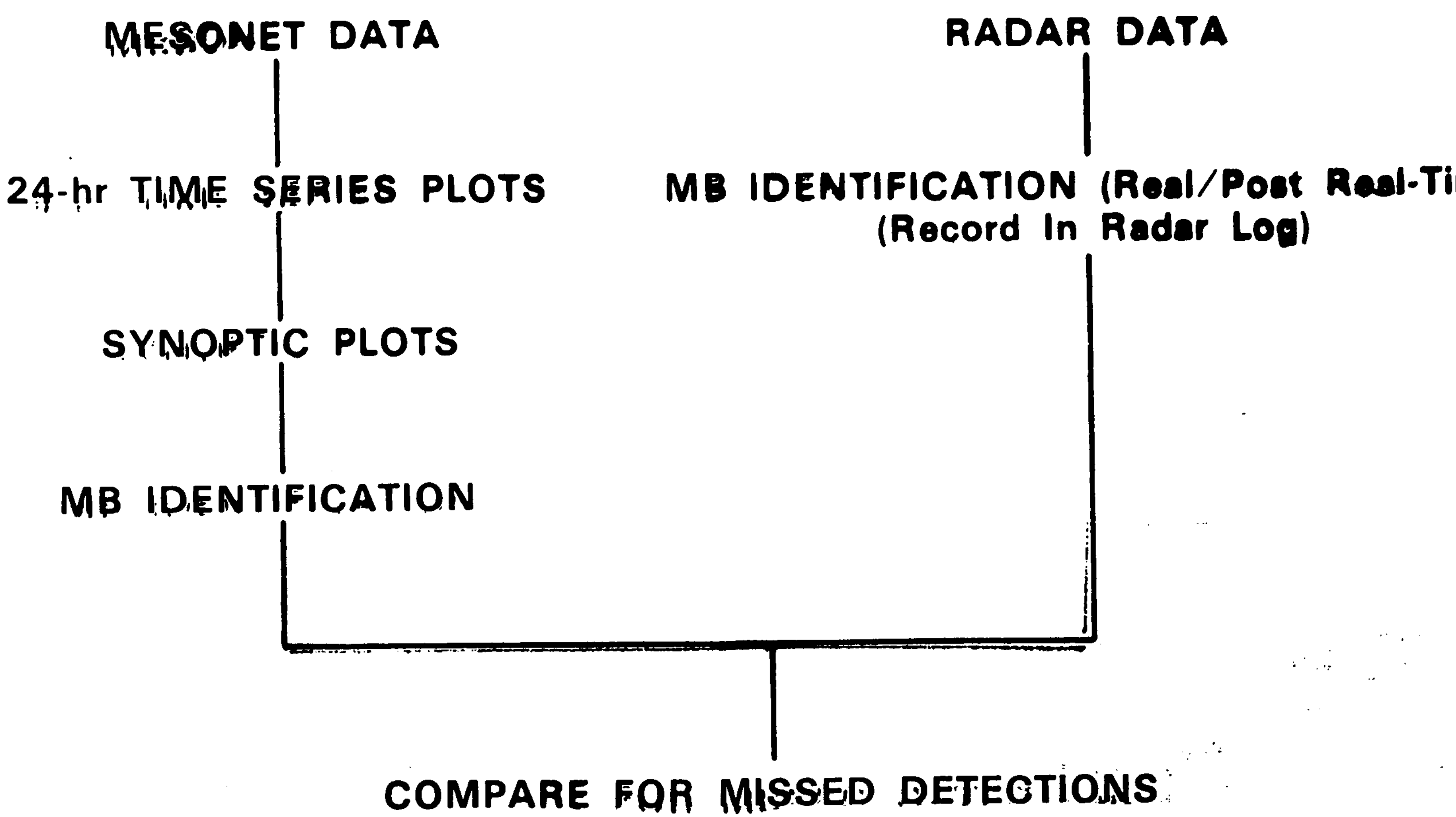
LOCATIONS OF WINDSHEAR EVENTS RECORDED IN RADAR LOG (April-November 1985)

FLOWS MEMPHIS TESTS



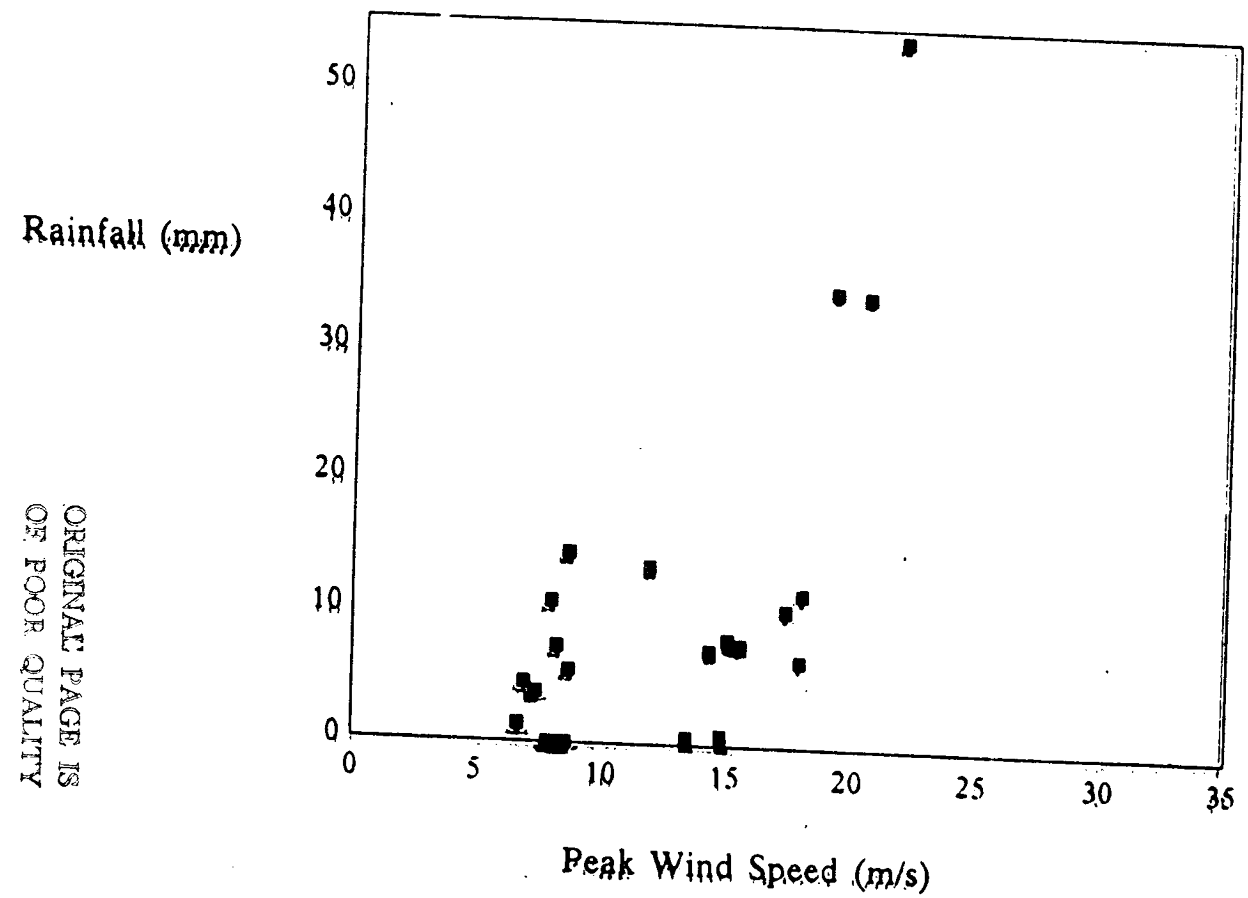
156491-N-01

RADAR/MESONET COMPARISON



FLOWS MESONET

TOTAL RAINFALL vs PEAK WIND SPEED IN MICROBURSTS



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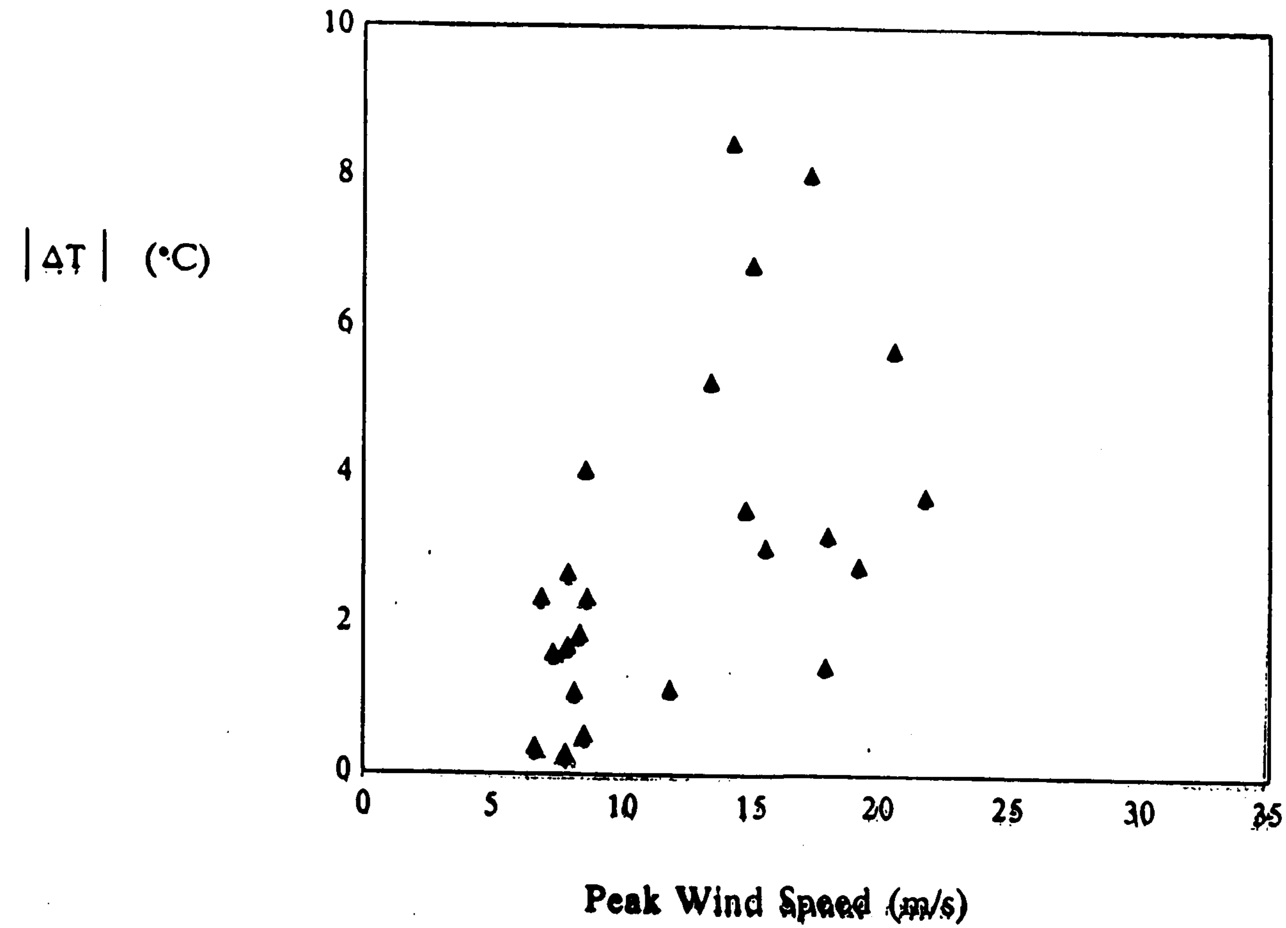
FLOWS MESONET

CHANGE IN TEMPERATURE vs PEAK WIND SPEED IN MICROBURS



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TECHNICAL REPORT STANDARD TITLE PAGE

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		6. Performing Organization Code
7. Author(s) R.E. Rinehart, J.T. DiStefano, and M.M. Wolfson		8. Performing Organization Report No. ATC-141
9. Performing Organization Name and Address Lincoln Laboratory, MIT P.O. Box 73 Lexington, MA 02173-0073		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA-01-80-Y-10546
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591		13. Type of Report and Period Covered Project Report
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15. Supplementary Notes

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, under Air Force Contract F19628-85-C-0002.

16. Abstract

During 1984 and 1985 M.I.T. Lincoln Laboratory, under the sponsorship of the Federal Aviation Administration (FAA) conducted a measurement program in the Memphis, Tennessee, area to study low-level wind shear events and other weather phenomena that are potentially hazardous to aircraft operations, with particular emphasis on those issues related to the Terminal Doppler Weather Radar (TDWR). The principal sensor for the measurement program was the S-band FAA-Lincoln Laboratory Testbed Doppler Weather Radar (FL2) which incorporates many of the functional features of the TDWR. Both FL2 and a C-band Doppler Weather Radar operated by the University of No h Dakota (UND) obtained reflectivity, mean velocity and spectrum width measurements with a radar geometry and scan sequences to facilitate determining the surface outflow features of microbursts at the anticipated TDWR ranges. A 30-station network of automatic weather stations (mesonet) collected 1-min averages of temperature, humidity, pressure, wind speed and direction, and total rainfall, plus the peak wind speed during each minute; this system operated from about March through November 1984 and 1985. Finally, the UND Citation aircraft operated two 3-week periods during 1985, collecting thermodynamical, kinematical and microphysical data within and around selected storms in the area as well as providing *in situ* truth for locations and intensity of turbulence.

This report describes the principal initial results from the Memphis operations, stressing the results from 1985 when the FL2 radar was fully operational. These results are compared to those from previous studies of wind-shear programs, e.g., NIMROD near Chicago, JAWS and CLAWS near Denver. During 1985, 102 microbursts were identified in real time along with 81 gust fronts. One of the dominant results is that most microbursts in the mid-south are wet; that is, they are accompanied by significant rainfall. This is in contrast, for example, to the results from Denver where more than half of all microbursts have little or no appreciable rain reaching the ground. Aside from this major difference, microbursts near Memphis were similar to those found elsewhere in the country in terms of wind shear magnitude. The report also gives more representative results from the aircraft operations and discusses the effectiveness of the groun ' ~lutter filters used on the FL2 radar.

17. Key Words		18. Distribution Statement
mesonet	NEXRAD	Document is available to the public through the National Technical Information Service, Springfield, VA 22161.
Doppler radar	turbulence	
microburst	clutter suppression	
wind shear	Low-Altitude Wind Shear	
gust front	aviation weather hazards	
Terminal Doppler Weather Radar		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	198	

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SECURITY CLASSIFICATION OF THIS PAGE

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Study of Microburst Detection Performance During 1985 in Memphis, TN

12. PERSONAL AUTHOR(S)

John T. DiStefano

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16. SUPPLEMENTARY NOTATION

None

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	low-level wind shear; microburst; Doppler weather radar; surface anemometers; mesonet; microburst outflow detection algorithm; radar/mesonet comparison; missed detections

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

This report focuses on the detectability of microbursts using pulse Doppler weather radars and surface anemometers. The data used for this study were collected in the Memphis, TN area during the FLOWS* project of 1985. The methods used for declaring a microburst from both Doppler radar and surface anemometer data are described.

The main objective of this report was to identify the results that were generated by comparing the 1985 radar detected microbursts (which impacted the surface anemometer system) with the surface mesonet detected microbursts. In so doing, the issue of missed microburst detections, for which there occurred two (both by the radar), is identified. Possible reasons as to why these two microbursts were not detected are discussed in detail.

*FAA/Lincoln Laboratory Observational Weather Studies

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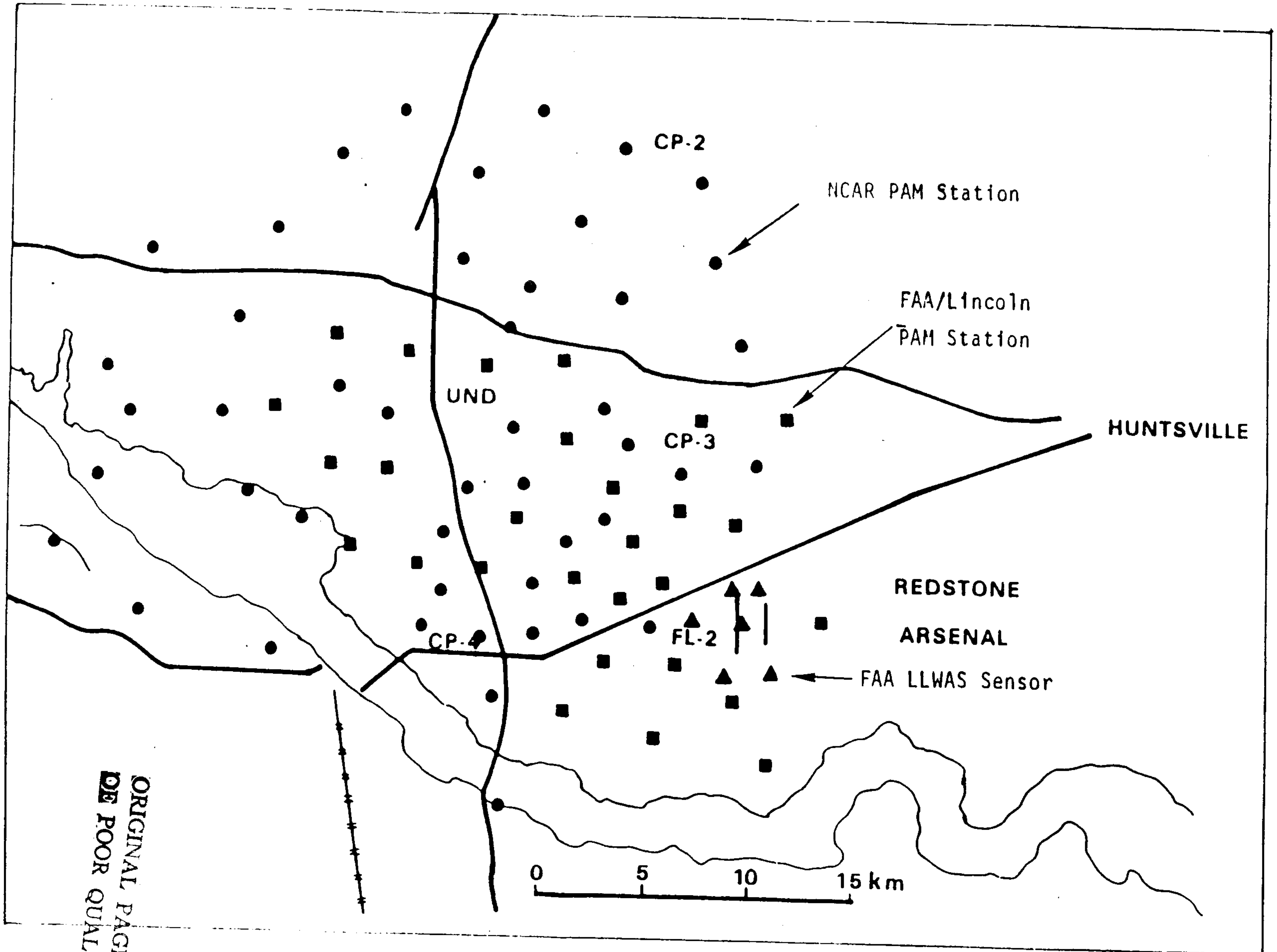
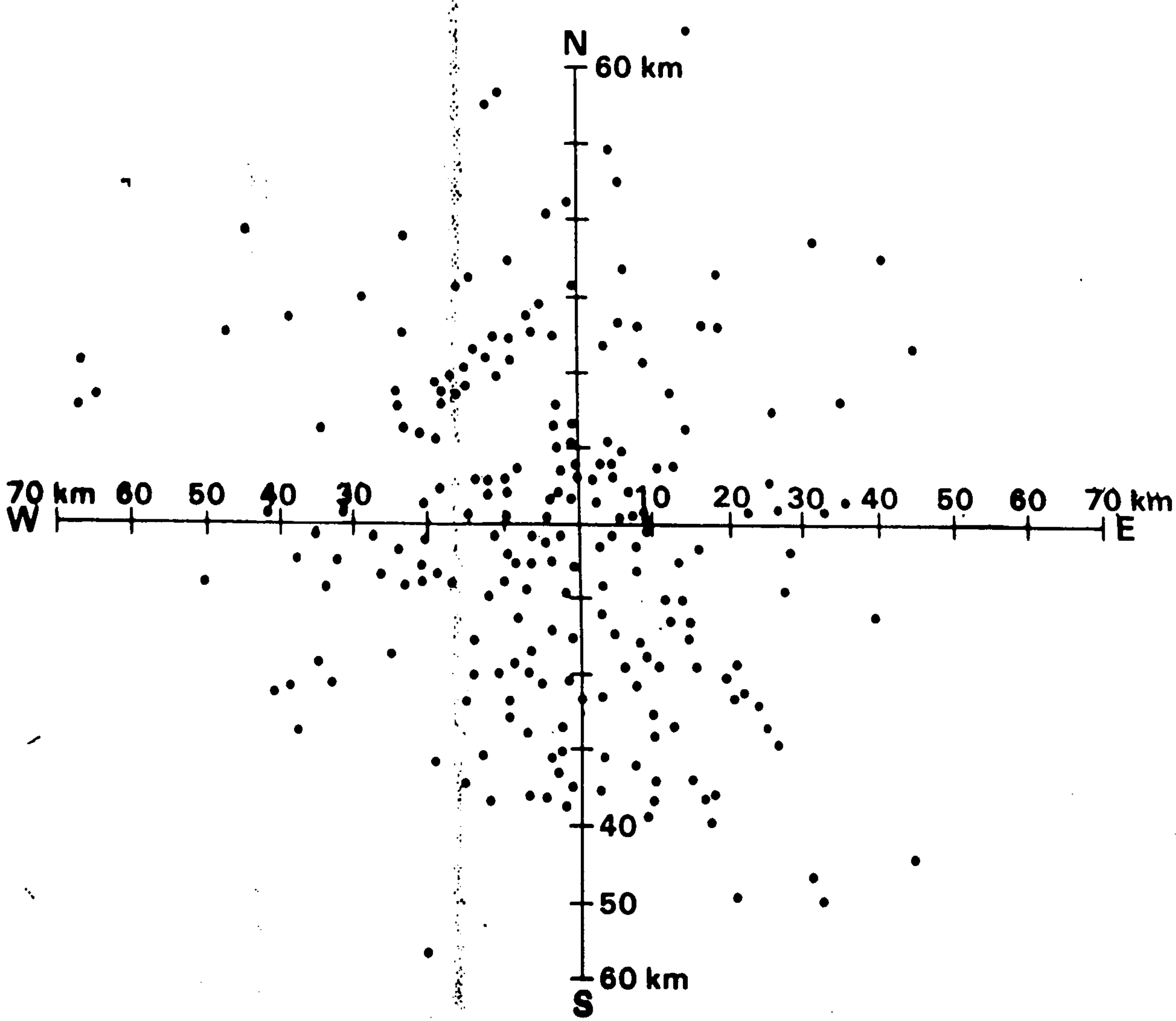


FAA/Lincoln Laboratory and MIST Systems at Huntsville, AL.

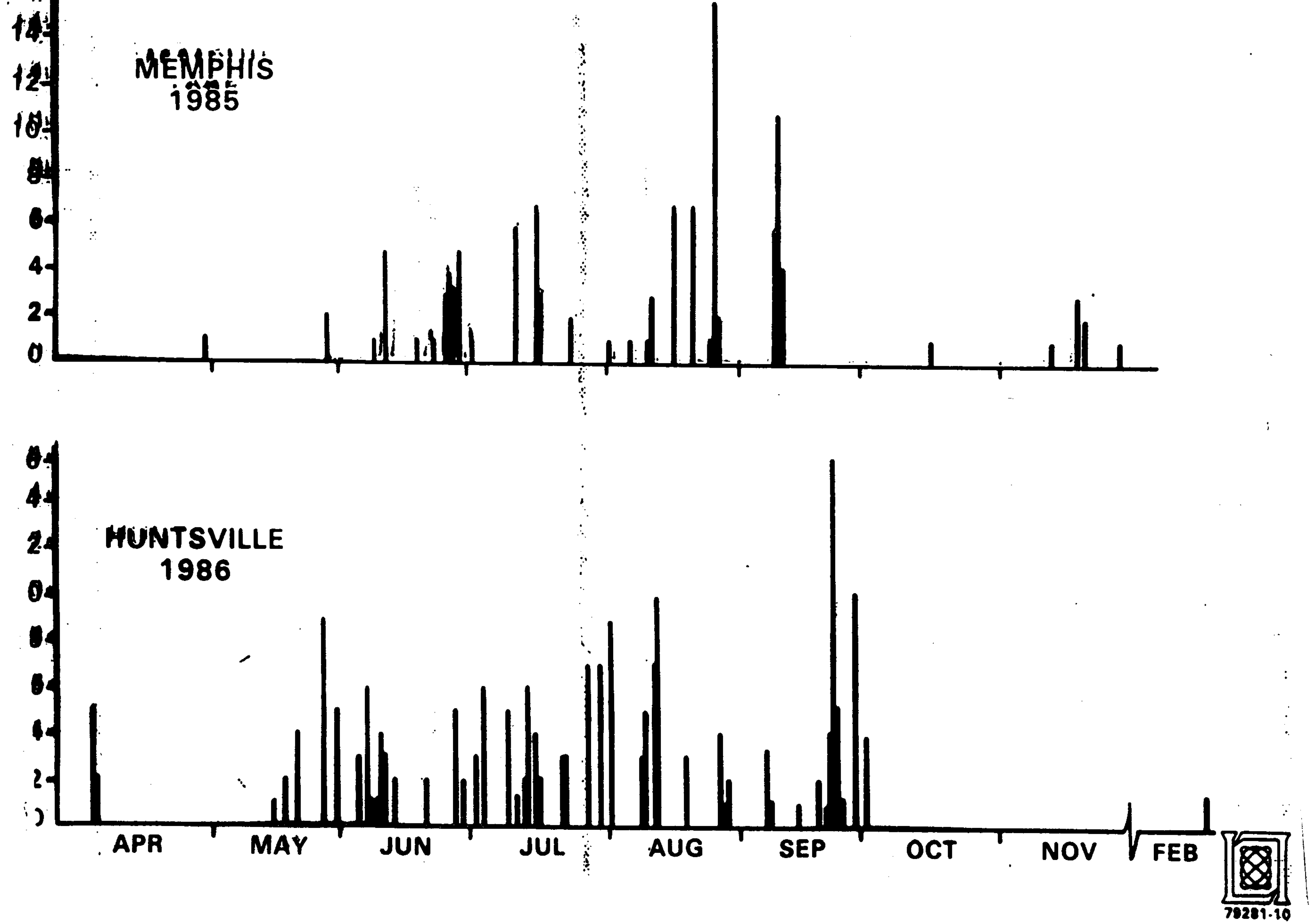
156976 N A B C

1986 MICROBURST LOCATIONS
HUNTSVILLE, ALABAMA

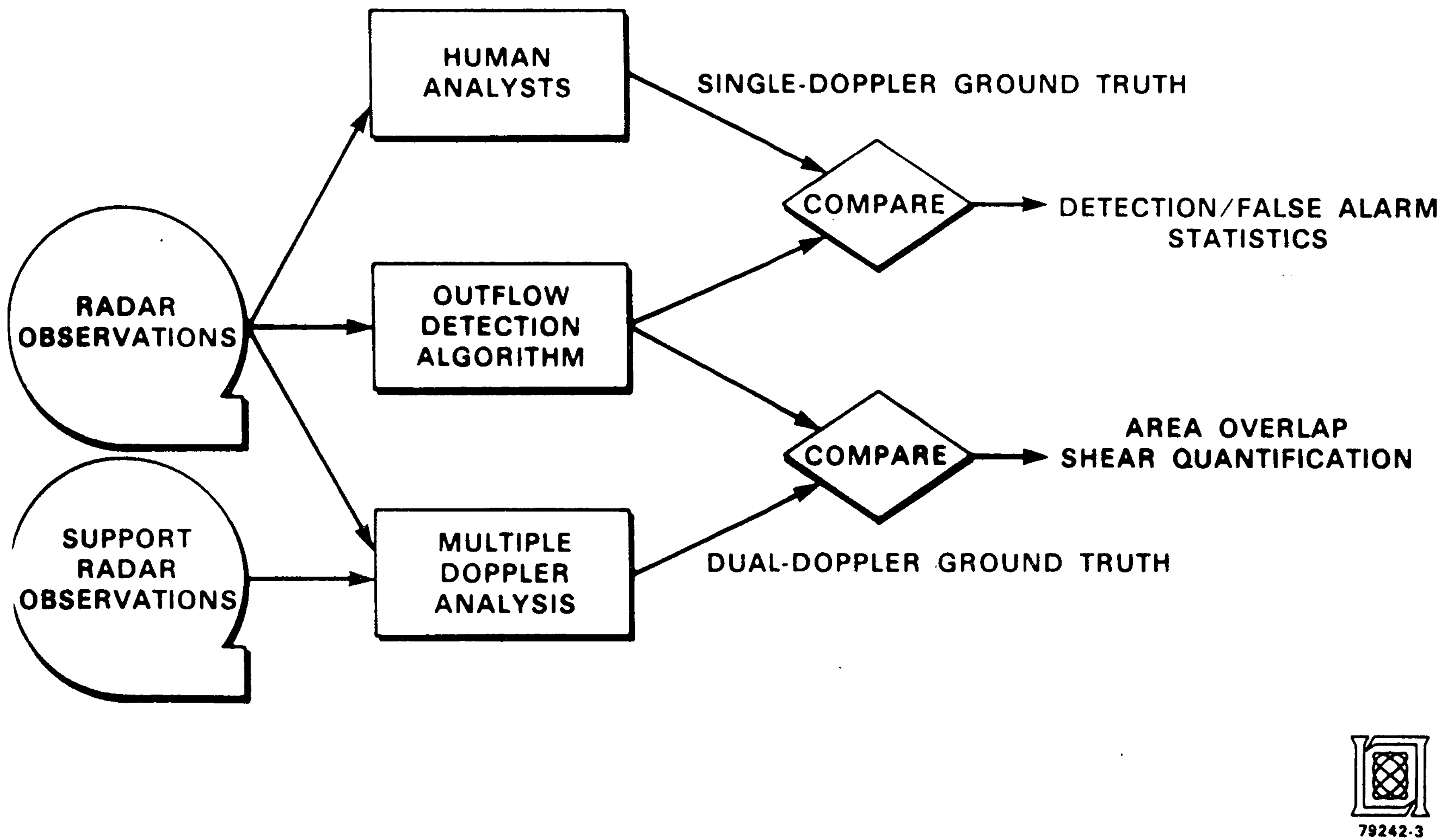


TEMPORAL DISTRIBUTION OF MICROBURSTS

NUMBER OF MICROBURSTS PER DAY



ALGORITHM SCORING PROCEDURE



1986 GROUND TRUTH DATABASE (10/7/87)

DATE	TAPES	DATA AVAILABLE(UT)	TRUTH TYPE	TRUTH PERIOD(UT)	WEATHER SYNOPSIS	TRUTH GRADE	TRUTHER	SCCS VERSION
JUNE 7	A-F	1625-2150(5.4)	Surface	1651-1749(1.0)		A	LL	2.3
JULY 1	A-I	1102-1425(3.3) 1732-2339(6.1)	Surface	1734-1940(2.1)		A	LL	2.3
JULY 6	A-E	1804-2228(4.4)	Precursors	2043-2121(0.7)		C	LL	2.3
JULY 11	A-E	0012-0107(0.9) 1205-1234(0.5) 1618-2245(5.5)	Precursors	0012-0034(0.3)		C	LL	2.3
			Precursors	1720-2042(3.3)		C	LL	
JULY 24	A-D	1733-2033(3.0)	Surface & Precursors	1756-1935(1.7)		B	NCAR	2.3
JULY 25	A-H	1448-2258(8.2)	Surface & Precursors	1853-2216(3.3)		A	NCAR	2.3
JULY 31	A-F	1637-2055(4.3)	Surface & Precursors	1741-1923(1.7)		A	NCAR	2.3
AUG 7	A-G	1802-0022(6.3)	Precursors	2109-2200(0.9)		C	LL	2.3
AUG 24	A-G	1749-2211(4.3)	Surface & Precursors	1845-2011(1.5)		A	LL	2.4
SEPT 5	A-D	0023-0147(1.4) 2044-2100(0.3)	Surface	2045-2058(0.2)		A	LL	2.3
SEPT 20	A-B	1708-2159(4.9)	Precursors	2113-2131(1.3)		C	LL	2.3
SEPT 21	A-H	1722-2201(4.7)	Surface & Precursors	1832-2046(2.2)		A	LL	2.3
SEPT 22	A-E	1923-0006(4.7)	Surface	2121-2354(2.5)		B	LL	2.3
SEPT 26	A-F	1638-2107(4.5)	Surface	1733-1945(2.2)		A	LL	2.3

Table D.2 Institutions* Responsible for Data Collection, Checking and Archival

Data Type	Data Collection	Data Checking	Generation of Level IIB Data	Data Archival
PAM-II surface mesonet	NCAR	NCAR, UC, UCLA, MSFC	NCAR	NCAR, NASA, UC
NASA surface mesonet	MSFC/UAH	MSFC/UAH	MSFC	MSFC
FAA surface mesonet	~~FAA~~ LL	~~FAA~~ LL	~~FAA~~ LL	~~FAA~~ LL
Raingage network	MSFC, TVA	MSFC	MSFC	MSFC
LLF network	MSFC	MSFC	MSFC	MSFC
Rawinsonde network	MSFC/UAH	MSFC/UAH	MSFC	MSFC
Special NWS rawinsonde	NWS	MSFC	MSFC	MSFC
U-2, ER-2 aircraft	MSFC, GSFC	MSFC, GSFC	MSFC, GSFC	MSFC, GSFC
T-28 aircraft	SDSMT	SDSMT	SDSMT	SDSMT, MSFC
P-3 aircraft	NOAA	NOAA, UC, MSFC	NOAA	NOAA, UC, MSFC
UND Citation	UND	UND	UND	UND
FAA Convair 580	FAA	FAA	FAA	FAA
CSU Cessna	CSU	CSU	CSU	CSU
BNA RADAP	NWS, MSFC	MSFC	MSFC, NOAA	MSFC
CP-2	NCAR	NCAR, CSU, PSU, MSFC	NCAR	NCAR, MSFC
CP-3, CP-4	NCAR	NCAR, UCLA, UC, FSU	NCAR	NCAR
FL-2	LL	LL	LL	LL
UND	UND	UND	UND	UND
Satellite image products	UND	UND	UND	UND
Derived satellite soundings	UW	UW, MSFC, GSFC	UW	UW, MSFC
Derived satellite winds		MSFC, UW	MSFC, UW	MSFC

*MSFC-NASA Marshall Space Flight Center, GSFC-Goddard Space Flight Center, NOAA-National Oceanic and Atmospheric Administration, NCAR-National Center for Atmospheric Research, FAA-Federal Aviation Administration, UC-University of Chicago, UCLA-University of California in Los Angeles, PSU-Penn State, CSU-Colorado State, SDSMT-South Dakota School of Mines and Technology, FSU-Florida State, UW-University of Wisconsin, LL-Lincoln Laboratory.

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5. REPORT DATE

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*S. F. Williams, *H. M. Goodman, *K. R. Knupp, & J. E. Arnold

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*Atmospheric Science and Remote Sensing Laboratory, Johnson Research Center, University of Alabama in Huntsville, Huntsville, AL 35899

16. ABSTRACT

During the period June through July 1986, NASA conducted the Satellite Precipitation and Cloud Experiment (SPACE) in the central Tennessee, northern Alabama, and northeastern Mississippi area. In addition to SPACE, the MIcroburst and Servere Thunderstorm (MIST) Program, sponsored by the National Science Foundation, and the FAA-Lincoln Laboratory Operational Weather Study (FLOWS), sponsored by the Federal Aviation Administration, operated concurrently under the acronym of COHMEX (COoperative Huntsville Meteorological EXperiment). The COHMEX field program incorporated measurements from remote sensors flown on high altitude aircraft (ER-2 and U-2), Doppler and conventional radars, rawinsondes, satellites, cloud physics research aircraft, and various surface observational systems.

This document contains a brief description of the field program and a daily data collection summary. Chapter 2 summarizes the program instrumentation and facilities, and includes sample selected data products. Chapter 3 provides a meteorological summary, operations overview, and an inventory of the data collected for each day of the field program. The purpose of this document is to provide the researcher and scientist with a tool to select data sets for case studies and instrument evaluation.

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SPACE
COHMEX
MIST
FLOWS
Data Inventory
Meteorological Observational Systems

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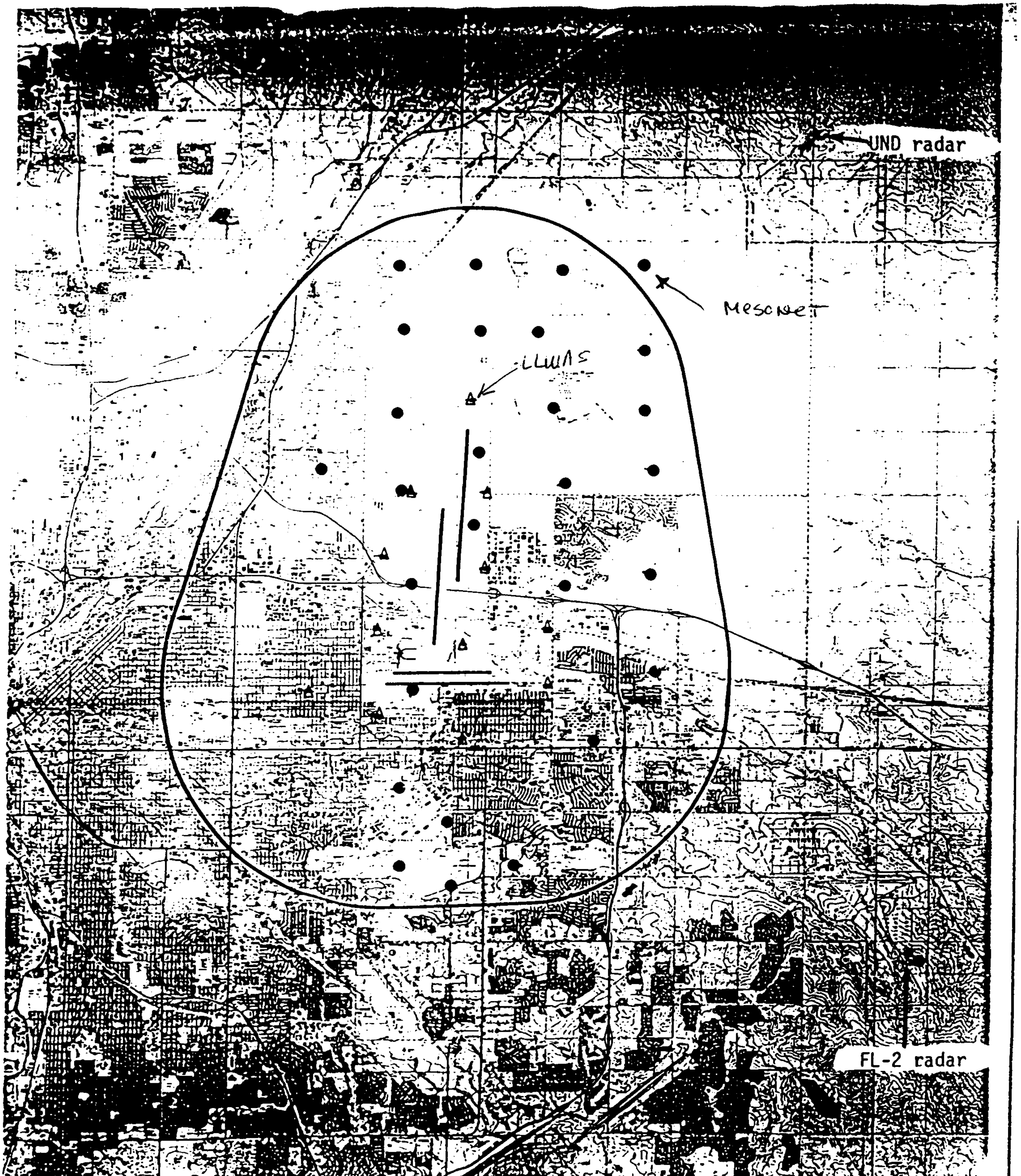

● surface weather stations   Δ Low-Level Wind Shear System anemometers

Terminal Weather Sensors Near Stapleton Airport for FAA 1987 Wind Shear Measurement Programs

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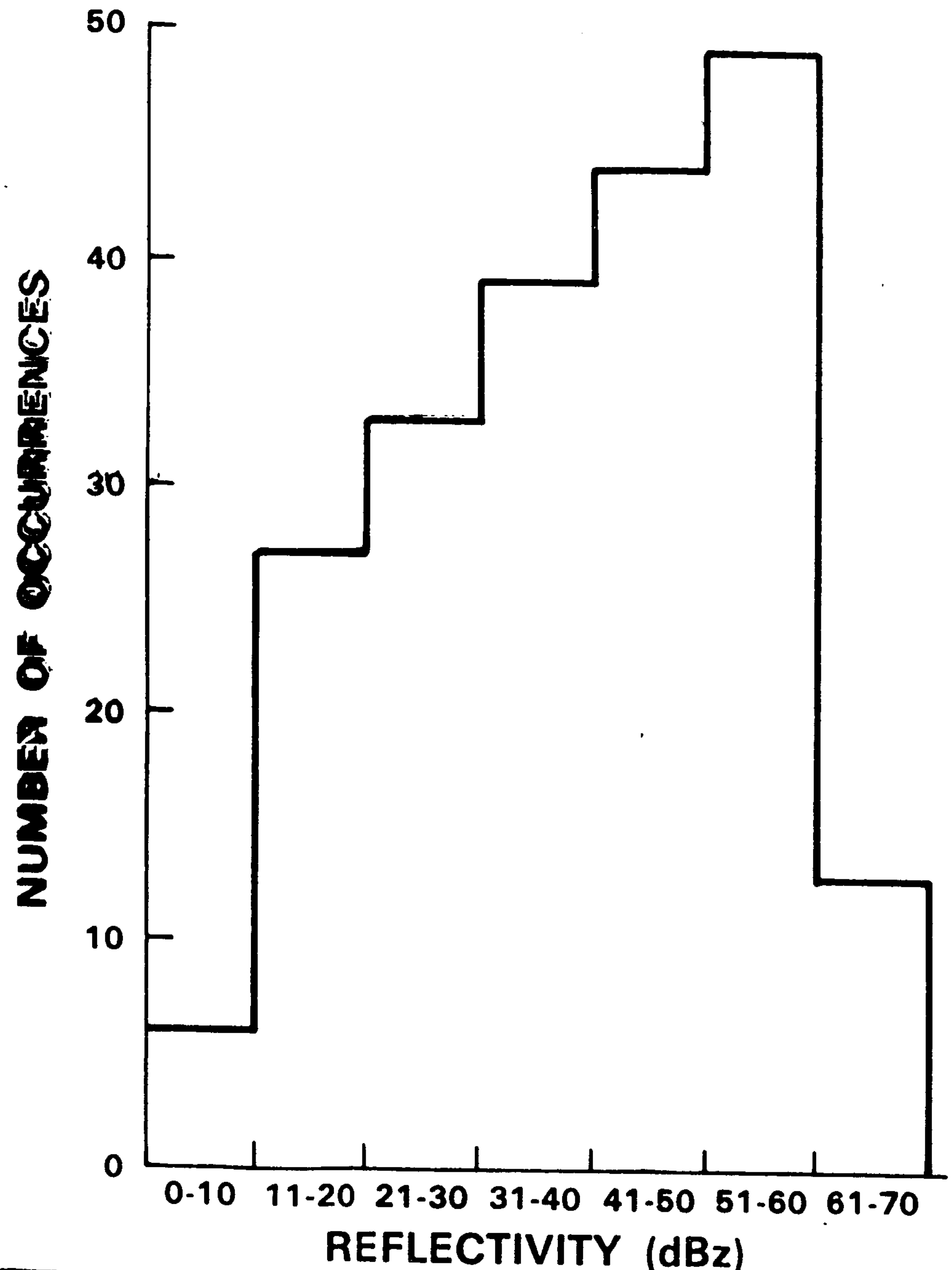
1987 DENVER MICROBURST REFLECTIVITIES



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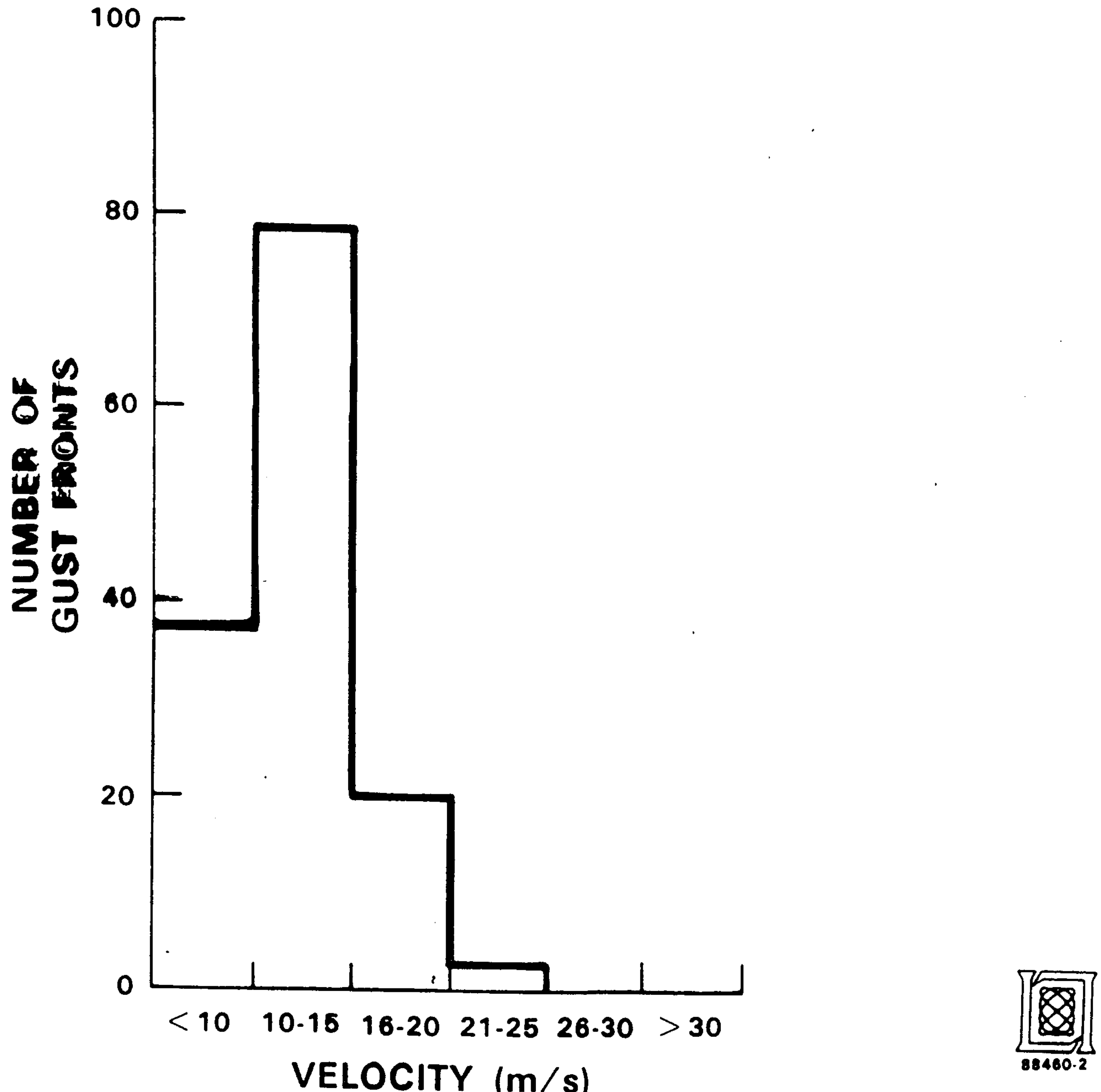
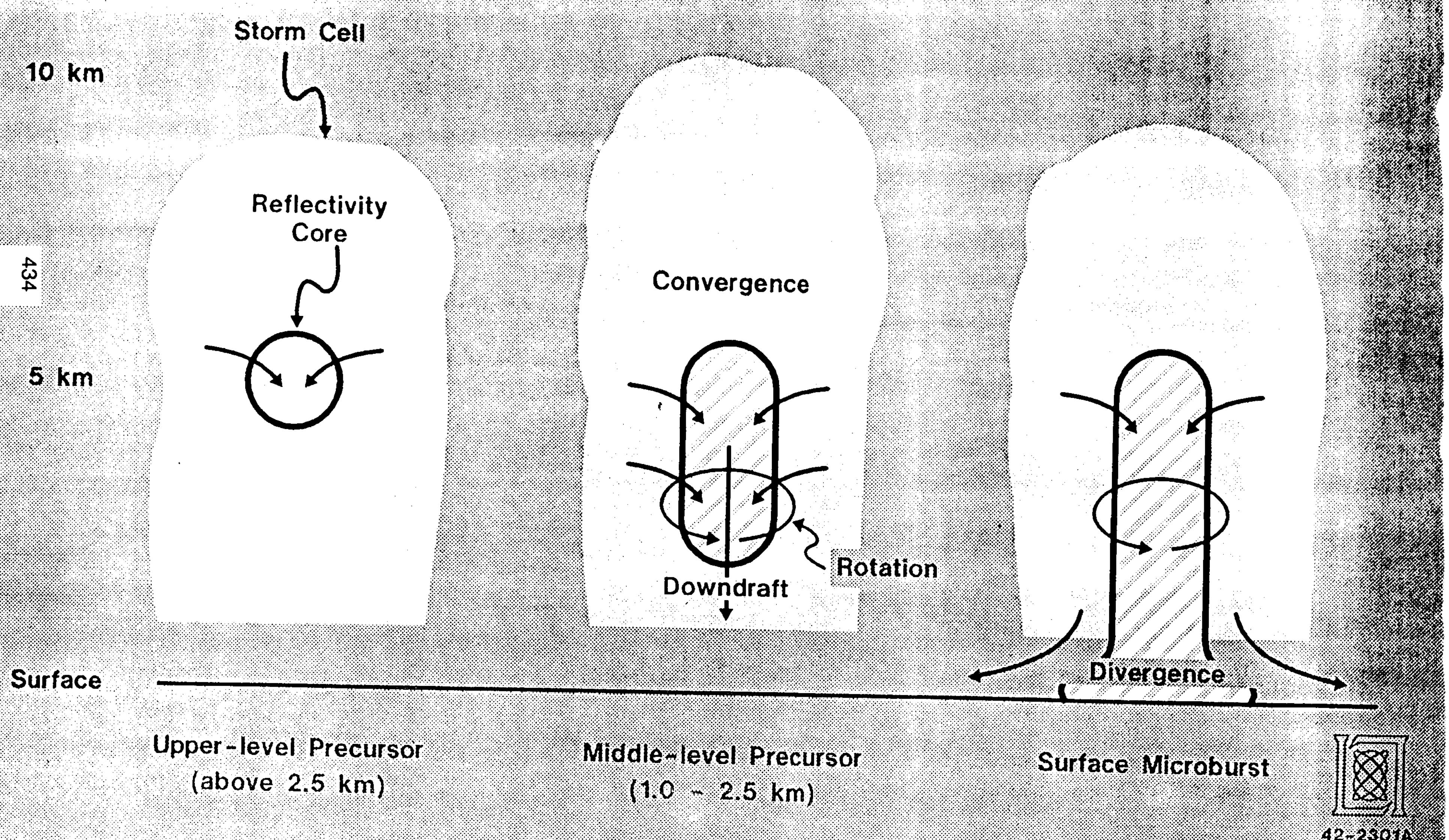
1987 DENVER GUST FRONT WIND SHEARS



1987 GROUND TRUTH DATABASE (10/7/87)

DATE	TAPES	DATA AVAILABLE(UT)	TRUTH TYPE	TRUTH PERIOD(UT)	WEATHER SYNOPSIS	TRUTH GRADE	TRUTHER	SCCS VERSION
MAY 23	A-E	2037-2344(3.1)	Surface	2100-2218(1.3)	TRW's	A	LL	1.6
MAY 28	A-D	2051-0048(4.0)	Surface	2149-0026(2.6)	TRW's	B	NCAR	1.8
MAY 30	A-C	2323-0205(2.7)	Surface	2346-0206(2.3)	Wet TRW's	B	NCAR	1.8
JUNE 7	A-D	2138-0238(5.0)	Surface	2323-0157(2.5)	High Refl., Line	A	LL	1.10
JUNE 10	A-D	1901-0017(5.2)	Surface	1919-2322(4.0)	Dry, Line	A	LL	1.10
JUNE 14	A-E	1933-0058(5.4)	Surface & Precursors	1953-0057(5.0)	Hot, TRW's	B	LL	1.6
JUNE 17	A-D	2103-0036(3.5)	Surface	2124-2333(2.1)	Weak TRW's	B	LL	1.1
JUNE 18	A-F	1934-0123(5.9)	Surface	2147-2327(1.7)	Supercell TRW	B	NCAR	1.5
JUNE 21	A-E	1759-0100(7.0)	Surface	1941-0045(5.0)	Dry MB's	B	LL	1.1
JULY 9	A-D	2051-0220(5.5)	Surface & Precursors	2342-0014(0.5)	Warm, TRW's	C	LL	1.1
AUG 25	A-I	1919-0047(5.5)	Surface	2309-0033(1.5)	Wet, Line	B	LL	1.1
SEPT 2	A-G	1722-0039(7.3)	Surface	2223-2310(0.9)	Line TRW's	B	LL	1.2

MICROBURST ALGORITHM FEATURES



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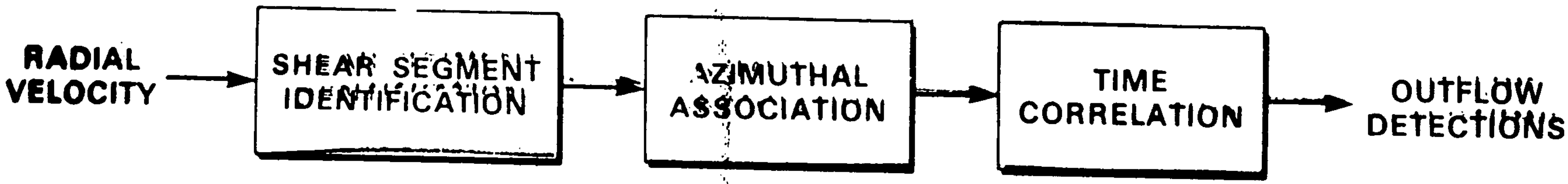
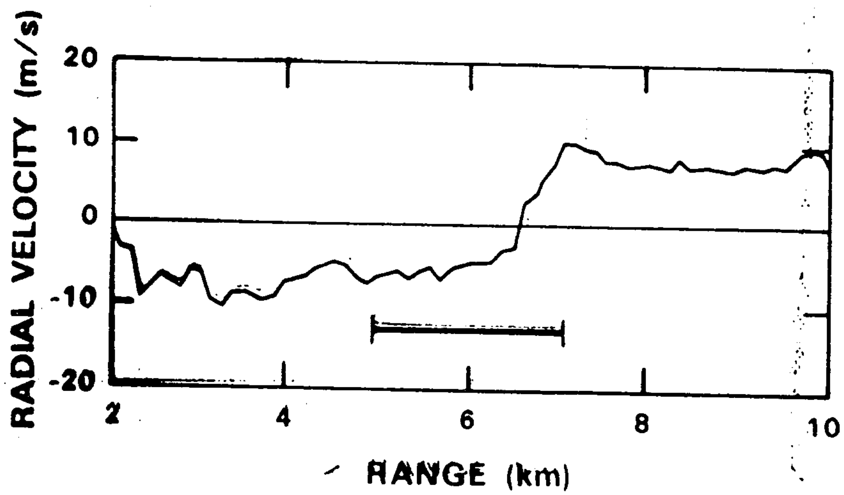
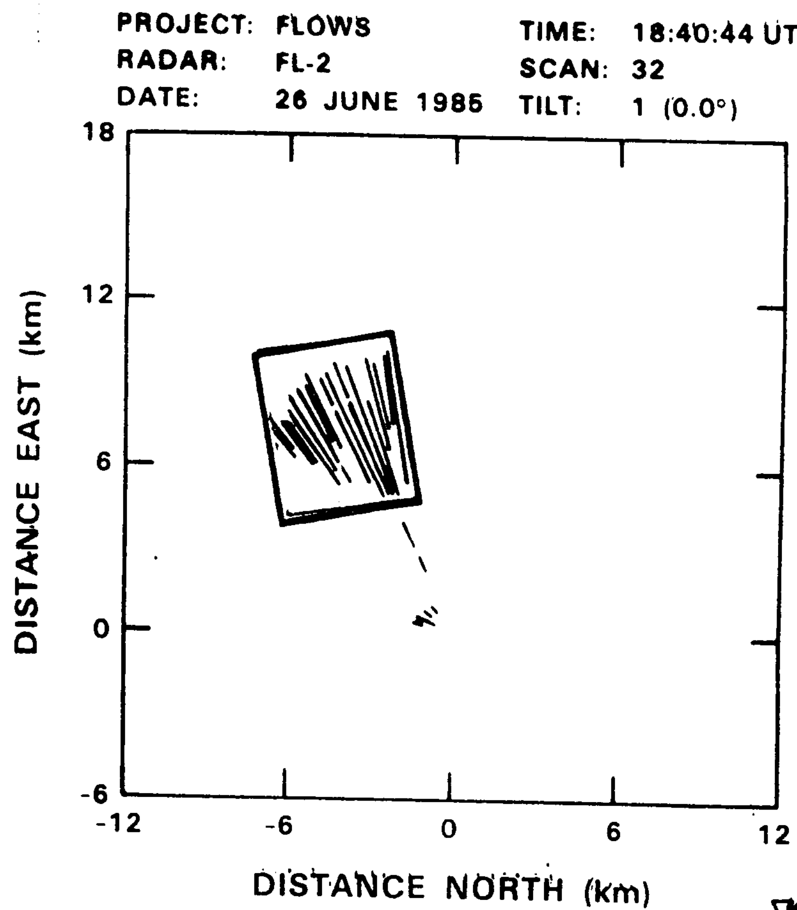
OUTFLOW DETECTION ALGORITHM







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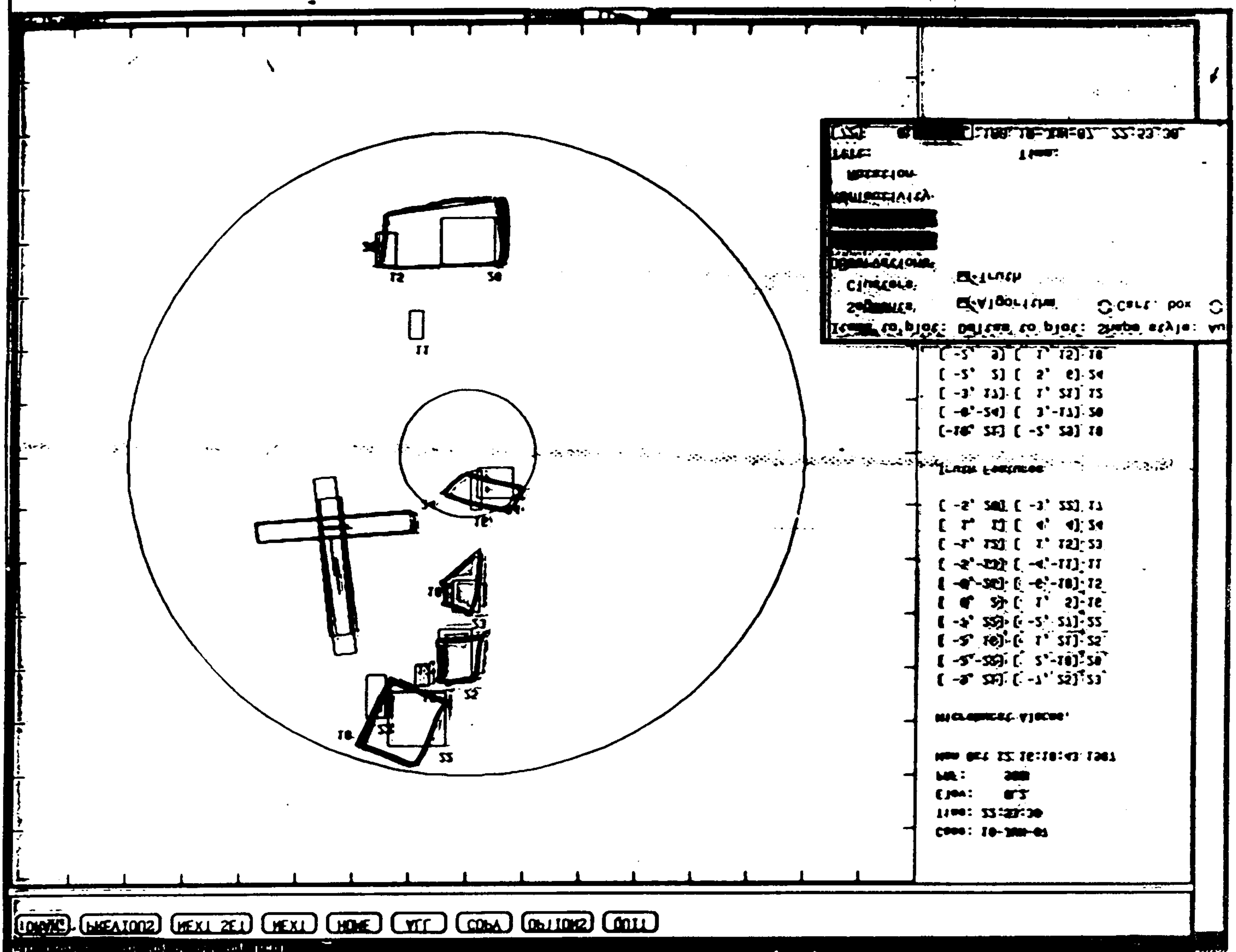

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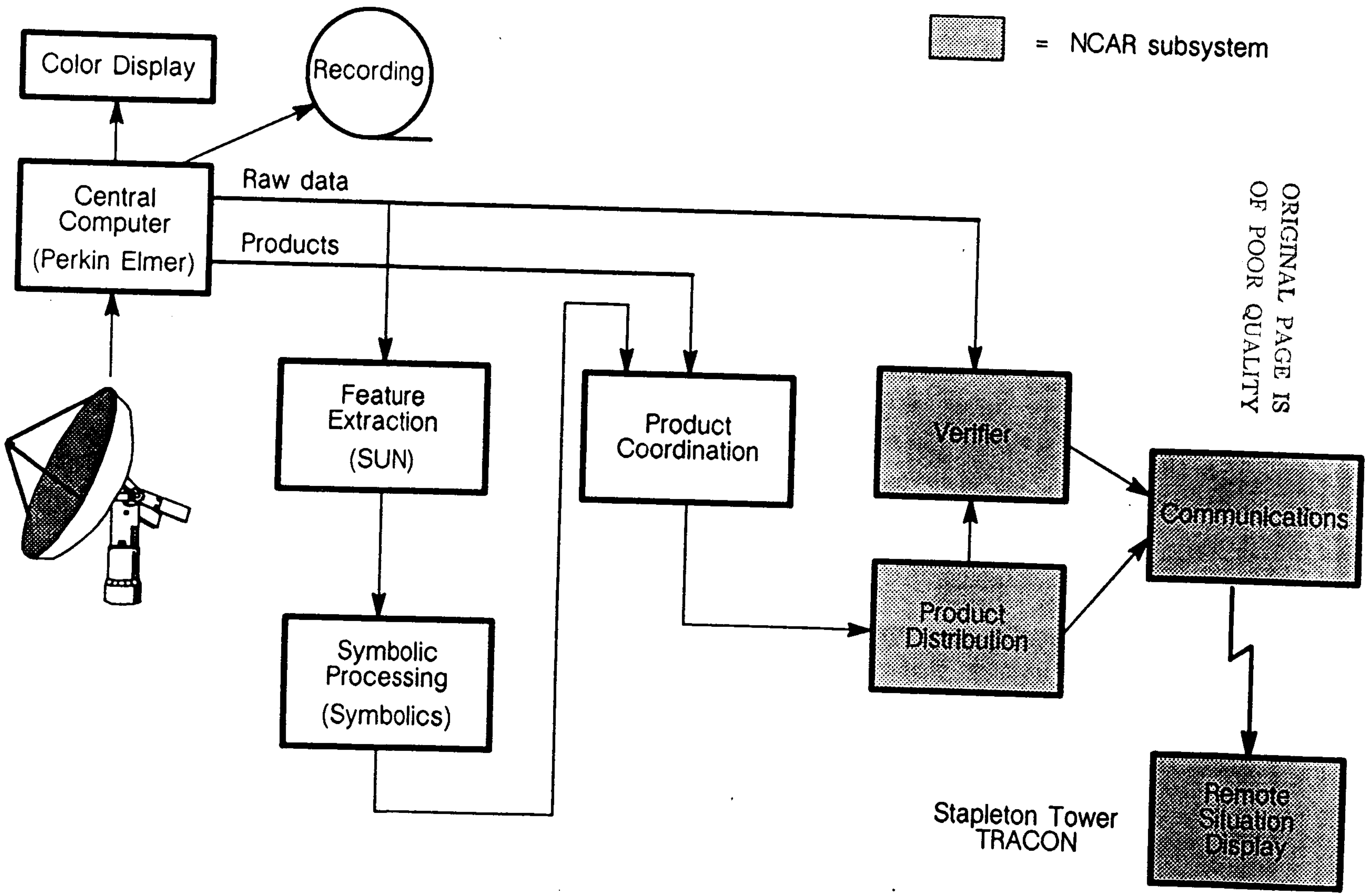
CONFIGURATION FOR REAL-TIME DEMONSTRATION



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24 June 1987
INFORMATION PACKAGE
FAA Doppler Weather Radar Tests
Denver, CO

Introduction

The Federal Aviation Administration (FAA) will be conducting an experimental measurement program using pulse Doppler weather radars during 1987 around Stapleton International Airport, Denver, CO to obtain information on low altitude wind shear phenomena and other terminal aviation weather hazards. The objective of the FAA measurement program for 1987 is to develop and validate techniques for the automatic detection of phenomena such as microbursts and gust fronts, turbulence and heavy rain. The results of this development program will be incorporated into the hardware and/or software components of the Next Generation Weather Radar (NEXRAD) and the Terminal Doppler Weather Radar (TDWR) systems which are being procured by the FAA.

A principal objective of the program is to develop techniques for detecting low-altitude wind shear* events which are potentially hazardous to aircraft taking off or landing at an airport. A particularly dangerous wind shear situation occurs when a microburst, or downburst, from a storm spreads out horizontally on reaching the ground as illustrated in Figure 1. When an aircraft encounters such a wind situation, there is often a rapid change from a headwind, which increases the lift of the airplane, to a tail wind, which reduces the lift of the airplane. In extreme cases, the sudden loss of lift from the tail wind can cause the airplane to crash. Encounters with wind shear events may have contributed to as many as 25 aircraft accidents worldwide over the past 10 years, resulting in over 500 fatalities.

Wind shear events can be caused by a number of meteorological situations. Thunderstorms often produce strong outflows and downdrafts which can spread out upon hitting the surface. Large thunderstorms are capable of producing long duration outflows, the leading edge of which are called "gust fronts." Gust fronts can extend several miles away from the rain area and last for periods as long as an hour or more.

Small storms and even relatively innocuous looking clouds are capable of producing small but intense downdrafts which can be just as hazardous (if not more so!) than those of their larger cousins. The smaller storms produce what has been termed "microbursts" by some scientists. These microbursts are often only a mile or two in diameter and last for as little as 5 minutes. Nevertheless, if a microburst were to occur near an airport while an aircraft is taking off or landing, an accident could result.

*The term wind shear is used to describe situations in which the wind encountered by an aircraft changes rapidly along the flight path. Not all wind shears are hazardous.

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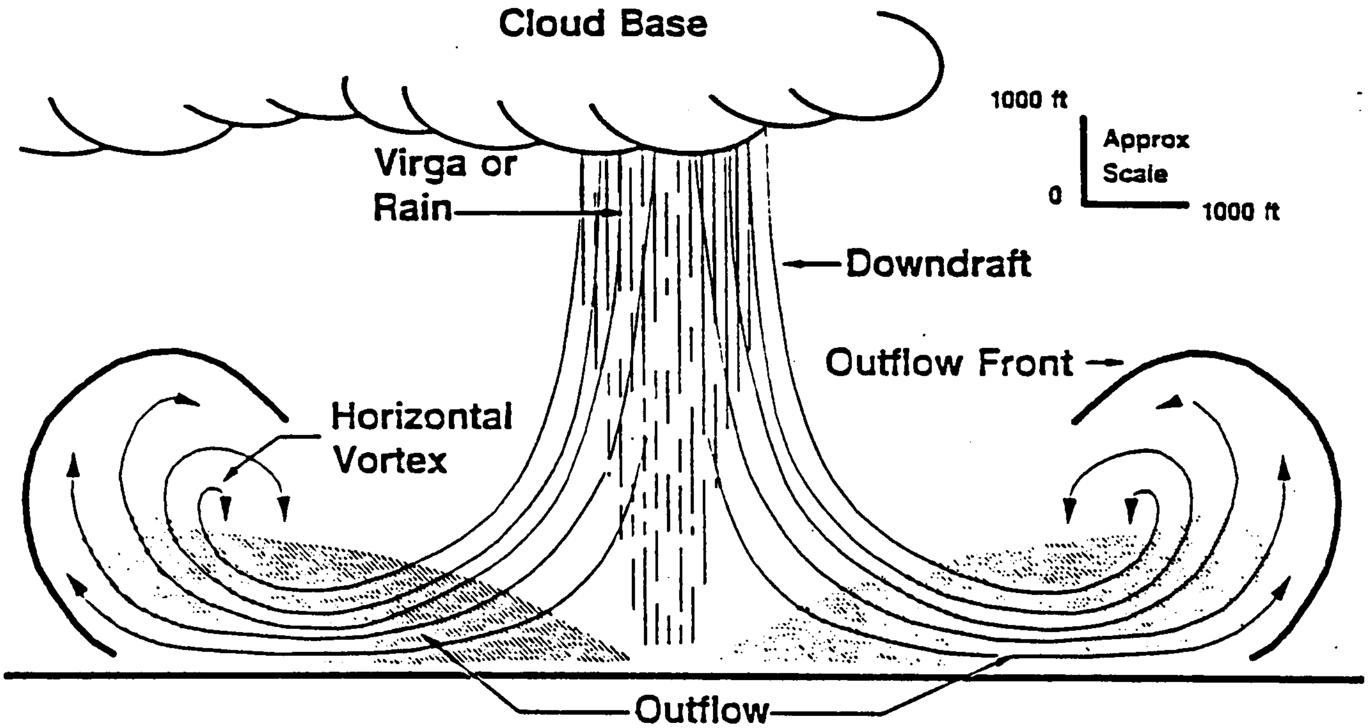


Figure 1. Symmetric Microburst. An Airplane Transiting the Microburst Would Experience Equal Headwinds and Tailwinds.

Low-altitude wind shear measurement and detection programs have been conducted at a number of locations (Chicago, Denver, Memphis (TN), and Huntsville (AL)) over the past few years. Denver was the site for:

1. The Joint Airport Weather Studies (JAWS) project, a study of the basic physics of microbursts conducted during the summer of 1982, and

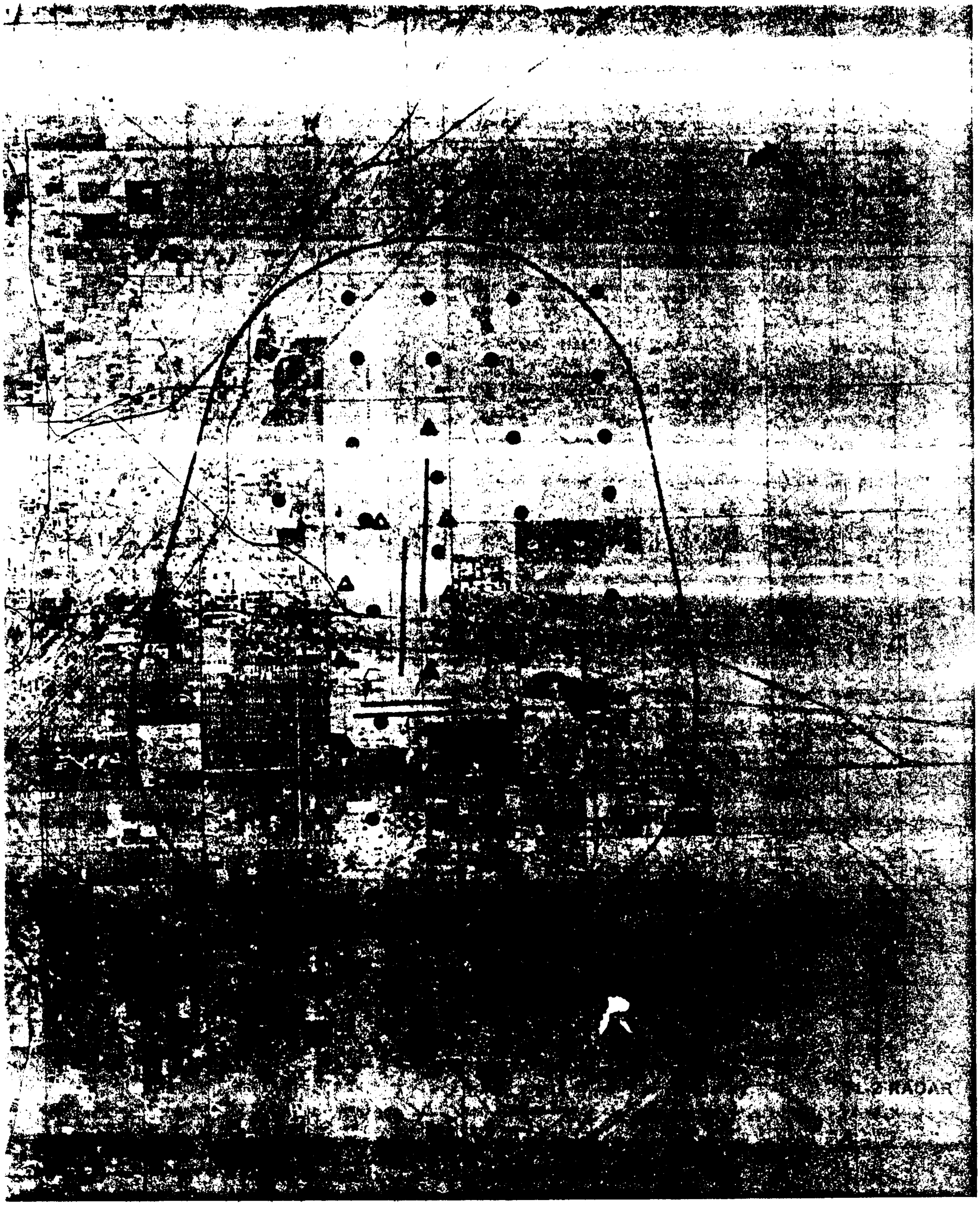
2. The Classify, Locate and Avoid Wind Shear (CLAWS) project, in which real time wind shear warnings were provided to the FAA control tower at Stapleton Airport during a 45-day period in the summer of 1984. The warnings were produced manually by research meteorologists from the National Center for Atmospheric Research (NCAR) who monitored data from a research Doppler weather radar. The warnings were provided to controllers who then informed pilots of hazardous weather events. CLAWS demonstrated that properly interpreted Doppler weather radars could provide operationally useful warnings of low-altitude wind shear.

The Denver Area Measurement Program

The measurement program in 1987 focuses on transitioning the scientific and operational knowledge gained in the previous measurement programs to a fully automated wind shear detection system.

Figure 2 shows the locations of the various ground weather sensing systems being used in the 1987 measurement program. The FAA test-bed Doppler weather radar developed and operated by the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) for the FAA will be the primary data collection tool for the measurement program. This S-band radar (designated by the letters FL-2 in Fig. 2 and shown in Fig. 3) uses a 28-ft. diameter antenna and a powerful signal processing system to record, process and display the Doppler measurements. This radar utilizes certain advanced digital processing techniques (e.g., digital clutter suppression filters and automatic choice of signal waveforms) which will be required in the systems the FAA is procuring. The FL-2 radar will be located on the Buckley Air National Guard airbase approximately 10 miles southeast of Stapleton Airport.

The second Doppler radar used in the 1987 testing will be a C-band system operated by the University of North Dakota (UND). This radar, located approximately 8 miles northeast of Stapleton (designated UND in Fig. 2), will provide additional confirmation of wind shear events near Stapleton as well as enable the FAA to determine the effects of wavelength on the measured reflectivity of wind shear events.



● SURFACE WEATHER STATIONS △ LOW-LEVEL WIND SHEAR SYSTEM ANEMOMETERS

Figure 2. Terminal Weather Sensors near Stapleton Airport for FAA 1987 Wind Shear Measurement Programs.

A network of 30 automatic weather stations (denoted by circles in Fig. 2) located in open areas is collecting data on temperature, humidity, pressure, wind speed and direction and rainfall, 24 hours a day. Data are averaged over 1-minute intervals and transmitted from each of the stations to the GOES-East geostationary satellite every half hour. The data are downlinked and provided to the project scientists by telephone line or computer tape for analysis or display. The wind data from the weather stations are used to validate the wind shear detection performance of the Doppler radars while the other weather station data are used to accomplish meteorological analyses of the wind shear events.

Additional information on the surface wind characteristics during wind shear events will be provided by data from the 12 FAA Low-Level Windshear Alert System (LLWAS) anemometers located about Stapleton (which are designated by triangles in Fig. 2).

UND is also operating its Citation jet aircraft equipped with instruments to measure the winds, temperature and humidity conditions near storms as well as the numbers and sizes of cloud droplets and raindrops encountered within storms. The Citation aircraft will furnish the data on the upper air environment associated with wind shear as well as direct measurements of turbulence to confirm the accuracy of Doppler radar-based turbulence detection algorithms.

The development and validation of algorithms to automatically determine the location and intensity of hazardous low altitude wind shear phenomena is a principal objective of the 1987 program. In June 1987, real time testing of the microburst outflow detection algorithm and the gust front detection algorithm will commence at the FAA test-bed radar site.

These algorithms, based on experimental programs and data analyses over the past few years by researchers at NCAR, NSSL, Lincoln Laboratory, and the University of Chicago will operate in real time on the FL-2 data processing system with the algorithm outputs being displayed on a color display workstation.

Researchers from NCAR, Lincoln Laboratory, and the National Severe Storms Laboratory (NSSL) will perform an initial evaluation of wind shear events and the algorithm performance in real time. A more detailed assessment of the weather phenomenology encountered and the algorithm performance (using data from the UND radar and surface weather sensors as well as FL-2 data) will be accomplished in post-measurement analyses.

The algorithms to be tested in 1987 have demonstrated operationally useful performance on wind shear events measured by the FL-2 system in 1985 near Memphis, TN and in 1986 near Huntsville, AL. The microburst events encountered in the humid southeast portion of the U.S. were typically accompanied by heavy rain. By contrast, many Denver area microbursts are associated with much lighter precipitation producing storms. Thus, it is

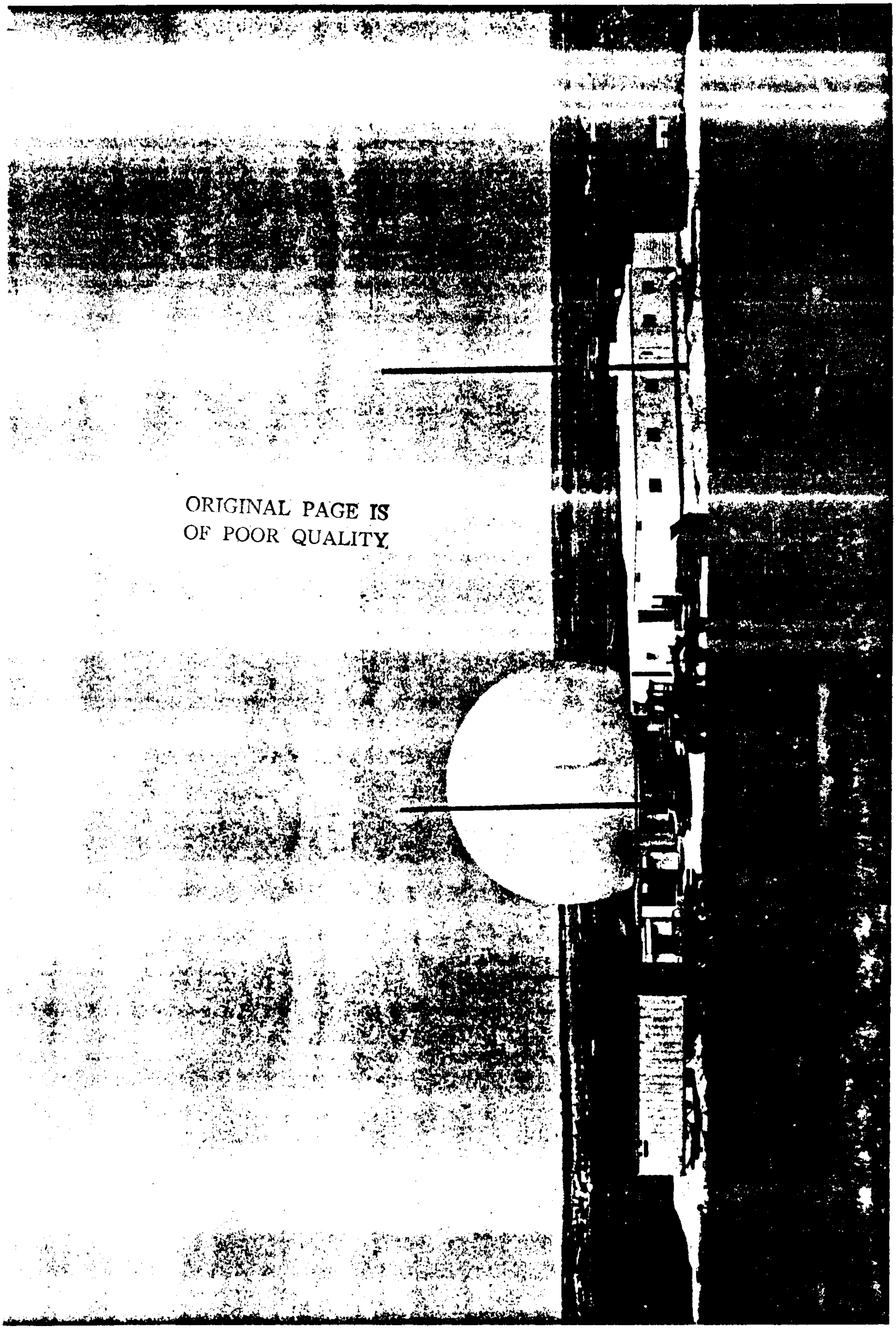


Figure 3. FAA testbed Doppler Weather Radar at Buckley ANG Airbase (Aurora, CO).

necessary to demonstrate that the algorithms have adequate performance on Denver wind shear events before the automated wind shear detection products can be provided to the air traffic controllers at Stapleton.

If an operationally useful detection capability is achieved against the Denver area windshear events measured in 1987, the FAA plans to conduct a full operational demonstration during 1988 in which automatically generated hazardous weather warnings will be provided to controllers for transmission to pilots.

Additionally, the 1987 program will explore the possibility of future enhancements to the near term automated products. A group of researchers from NCAR will review the FL-2 data in real time to determine whether expert radar meteorologists can reliably predict the imminent (e.g., 5-10 minutes) occurrence of microbursts and/or the development of thunderstorms.

FAA Weather Radar Procurement

The Federal Aviation Administration is participating in 3 weather radar programs. These are the Next Generation Weather Radar (NEXRAD), terminal NEXRAD, and Terminal Doppler Weather Radar (TDWR). The NEXRAD Program is a joint effort of the FAA, the National Weather Service, and the Air Force to develop and procure a national network of weather radars.

The terminal NEXRAD Program involves the use of 17 NEXRAD units reconfigured for terminal operations and installed near major airports such as Denver Stapleton, Dallas-Fort Worth, and Chicago. These radars will be operated for an interim period until the TDWR is available after which the terminal NEXRAD systems will be reconfigured as standard NEXRAD systems and relocated to Alaska, Hawaii, and the Caribbean.

The TDWR systems being procured by the FAA will provide pilots and controllers with an indication of wind shear and other hazardous weather conditions. These systems will be installed at major airports beginning about 1992.

The Denver test program supports all of these activities.

Details on the scope and time schedule of the FAA weather radar program can be obtained from Mr. Donald Turnbull [telephone (202) 267-8429].

Additional information on the Lincoln Laboratory, NSSL, and NCAR participation in the above measurement program can be obtained from Drs. James Evans [(617) 863-5500 X814-433], Dusan Zrnic' [(405) 366-0403] and Cleon Biter [(303) 497-8937], respectively.