Weather Radar Manual

(WBAN)

PART A

August 1967

RECORD OF CHANGES

Supplement or change no.	Date effective	Pages affected	Initials	Date entered
Change No. 1	1/1/68	13-1, 13-2, 13-3, 13-4	RJB	12/13/74
Change No. 2	7/15/70	5-1, 5-4, 5-2, 5-5, 6-1, 6-1A, 8-1, 12-2, 13-1, 13-2, 13-3, B5-16a	RJB	12/13/74
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U.S. DEPARTMENT OF COMMERCE ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

U.S. DEPARTMENT OF THE AIR FORCE Air Weather Service

U.S. DEPARTMENT OF THE NAVY Naval Weather Service

Weather Radar Manual

(WBAN)

PART A

National Weather Radar Network
Observing and Reporting Procedures

WASHINGTON, D.C.

August 1967

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PREFACE

This manual was developed by an interagency working group representing the Department of Commerce (ESSA - Weather Bureau), Air Force (Air Weather Service), and Navy (Naval Weather Service). The working group was organized and functioned under the auspices of the Sub-Committee on Basic Meteorological Services of the Interdepartmental Committee for Meteorological Services.

The manual was designed to provide standard observing and reporting instructions to radar stations assigned to the National Synoptic Weather Radar Network and, also, to serve as a convenient reference on the fundamentals and applications of weather radar for both network and local use service.

Plan of the manual:

Part A - National Weather Radar Network Observing and Reporting Procedures.

Part B - Weather Radar Fundamentals and Applications.

Part C - Equipment calibration and operation particularized for the various types of radars in the national network and local use service. Each agency will provide internal instructions in this area. It is expected that immediate requirements will be fulfilled by adoption of existing technical manuals and other instructions.

Part A modifies and continues the observing and reporting procedures formerly published in the Weather Surveillance Radar Manual, a Weather Bureau publication, and Part B is based mainly on Air Weather Service Technical Report 184, General Application of Meteorological Radar Sets.

Revisions and additions to the Weather Radar Manual will be published in the form of numbered amendments consisting of additional or substitute pages.

NATIONAL WEATHER RADAR NETWORK
OBSERVING AND REPORTING PROCEDURES

PAGE

NATIONAL WEATHER RADAR NETWORK

OBSERVING AND REPORTING PROCEDURES

1. GENERAL

Stations assigned to the National Weather Radar Network are expected to maintain radar surveillance, to file operational status reports, to evaluate and interpret radar indications, and to encode and transmit scheduled and special observations. Exceptions to this program and deviations from the procedures that follow should be limited to situations where specific authority is provided by the operating agency.

2. PERFORMANCE OF EQUIPMENT

Operating personnel should be alert to detect substandard performance of their equipment and they should be prompt in initiating whatever corrective action is required. Test and calibration procedures to insure correct calibration and orientation and proper operation of all radar components will be specified in appropriate technical instructions issued by the operating agency. These tests and calibration procedures should be conducted systematically and should include RHI calibration, azimuth and range calibration to standard levels of accuracy, and system calibration to permit quantitative measurement of reflectivity as specified for the particular radar.

3. EVALUATION, ENCODING, AND RECORDING OF DATA

3.1 Echoes to be Reported. Include all precipitation echoes and all fine lines associated with meteorological discontinuities in radar reports. Report other phenomena as an added remark if the information is determined to be appropriate and useful.

3.2 Recording Observations. Record observations on the Radar Weather Observations Form (WBAN Form 60). Use a separate line for each related group of echoes except continue in appropriate spaces of the next lower line if more than five direction-distance groups are needed or if more space is needed for remarks. Where recorded data are not intended for transmission over the primary communications channel, enclose the entries in parentheses. (Instructions that follow are generally arranged in the same order as the columns of the Radar Weather Observations Form.)

3.3 Disposition of Forms. Retain a carbon copy of WBAN Form 60 for at least three months after the end of the month of record and as long thereafter as required for local or agency purposes. Mail the original WBAN Form 60 addressed to:

National Weather Records Center
Federal Building
Asheville, North Carolina 28801

Attention: Climatic Information Section
(Radar Observation Forms)

Stations regularly involved in recording radarscope data by means of time-lapse photography should mail their forms each Friday and by the second working day of each month. Include forms pertaining to the preceding period including Thursday or the last day of each month. If forms pertaining to only one or two days are involved, they may be retained until the next scheduled mailing. In order to conform to the mailing schedule, start a new observation sheet at 0000 GMT each Friday and at 0000 GMT on the first day of each month. Stations not regularly involved in time-lapse photography should mail their forms by the second working day of each month and should include forms pertaining to the previous month (GMT). Forms may be folded once but should not be creased.

3.4 Radarscope Photography. Network radar stations regularly engaged in data recording by means of time-lapse photography should operate their cameras on the schedule given in Table 3-1.

Completed film rolls should be forwarded immediately to the National Weather Records Center for processing. A transmittal label (WB Form 610-26) should be filled in completely; the "Remarks" section should contain notes that will help the film editor evaluate the film. Note the aperture used, the detection of hooks, the occurrence of tornadoes and flash floods, malfunctions affecting film quality or coverage, copies required, and the location on the roll of any test sections. Include a separate memorandum if more space is needed for pertinent film notes. To prevent later obliteration, do not apply tape or glue to the face of the transmittal label. Insert the film can in the original box, attach the transmittal label to the box, wrap the box securely with heavy paper and attach a mailing label addressed:

National Weather Records Center
Federal Building
Asheville, North Carolina 28801

Attention: Climatic Information Section
(Radarscope Film).

Table 3-1. Frequency and Range For Radarscope Photography

Operating Condition	Interval	Range
Radar off or in standby mode	--	--
Radar Operating for any reason - no reportable echoes	15 minutes	Maximum
Reportable echoes detected - no severe weather	5 minutes	Maximum, 125, or 100 n. mi.
Severe thunderstorms occurring or expected	1 frame per 2 antenna revolutions	Minimum to encompass significant event
Echoes associated with tropical storm or hurricane within range	1 frame per 2 antenna revolutions	Maximum
Aircraft in distress or aircraft accident within range (see paragraphs 12.3.3 and 12.3.4). Continue special photography for 1/2 hour after event	1 frame per 2 antenna revolutions	Minimum to encompass significant event

4. DATE, TIME

4.1 Accuracy of Time. It is important that all times associated with radar observations be accurate to the nearest minute. Each station's observation program must include a reliable procedure for obtaining time-checks and monitoring clocks used in any phase of radar observation and data collection.

4.2 Ascribed Time of Observation. Enter the date and ascribed time of observation in terms of the 24-hour clock system and Greenwich Mean Time. The ascribed date and time of observation will be the time of last entry. The date and time identifying status reports and other entries on the observation form should be determined and entered similarly.

4.3 Currency of Reported Data. As a general rule all elements in an observation should have been observed within the previous 15 minutes relative to the ascribed time of observation. Otherwise, the phenomena included in an observation should be reported as a remark and the time of observation should be included.

5. CLASSIFICATION OF ECHOES

5.1 Character of Echoes. Echo patterns will be classified in terms of the echo systems listed and defined in Table 5-1. Classification of echoes for reporting purposes involves consideration of configuration, coverage, continuity of pattern, and meteorological processes. Ideally, echoes should be grouped in order to reflect all of these considerations and yet provide a practical and concise means of conveying operational data that is sufficiently useful. It finally becomes a matter of judgment to avoid, on one hand, encoding an unwieldy number of echo groups or, on the other, reporting excessively large groups that convey very little useful information. Select an echo system designation for each group of echoes from the list of Table 5-1 and enter its contraction in Column 3 of the Radar Weather Observations Form.

5.1.1 Lines. Encode an echo pattern as a line rather than an area when its length-to-width ratio is at least 5 to 1 and its length is at least 20 miles.

5.1.2 Systems Included in or Associated With Other Systems. Report separately echo systems having distinct and significant characteristics even though they are wholly or partly contained in, or associated with, other reported systems. A line within an area, an identifiable group of thunderstorms within a shower area, and a rain area trailing a line of thunderstorms, are examples of interrelated systems that should be reported separately.

*5.1.3 Elevated echoes. Use the contraction "LYR" in Column 3 to report stratified elevated echoes if their base is uniform. Report the height of the base of such echoes, to the nearest thousand feet, in hundreds of feet, by a remark in Column 10. Observed height values of echo bases should be corrected for height of the antenna, earth curvature, standard atmosphere refraction, and half of the nominal beam width (a positive factor). A complete report of a stratified elevated system might appear in transmitted form as:

LYR⊕ R-/NC 274/35 110/40 225/25 2712 ELEMENTS 2415 MAX TOP 210 AT 233/22 BASE 90.

Because of vertical beam width distortion, earth curvature, and height variability, elevated echo systems are sometimes unusually difficult to evaluate and describe. Report such systems by brief remarks in Column 10 rather than in the standard reporting format.

Table 5-1. CHARACTER OF ECHOES

Echo System	Definition	Contraction
*Isolated echo	Independent convective echo(es)	CELL(S)
Widely scattered area	Related or similar echoes covering less than 1/10 of the reported area	AREA WDLY⌽
Scattered area	Related or similar echoes covering 1/10 to 5/10 of the reported area	AREA⌽
Broken area	Related or similar echoes in a pattern that covers 6/10 or more of the reported area but contains breaks or corridors.	AREA⦷
Solid area	Contiguous echoes covering, usually, more than 9/10 of the reported area	AREA⊕
Line of widely scattered echoes	Related echoes in an extended pattern covering less than 1/10 of the reported area	LN WDLY⌽
Line of scattered echoes	Related echoes in an extended pattern covering 1/10 to 5/10 of the reported area	LN⌽
Broken line of echoes	Related echoes in an extended pattern that covers 6/10 or more of the reported area but contains breaks or corridors	LN⦷
Solid line of echoes	Contiguous echoes in an extended pattern covering, usually, more than 9/10 of the reported area	LN⊕
Spiral band area (broken or scattered)	Echoes associated with tropical storms, hurricanes, or typhoons and systematically arranged in curved lines. This grouping may include a wall cloud.	SPRL BAND AREA (⦷ OR ⌽)
Stratified elevated echo	Precipitation aloft	LYR (⌽, ⦷, OR ⊕)
Fine line	Narrow nonprecipitation echo pattern associated with a meteorological discontinuity such as the cold air outflow in advance of a squall line or the leading edge of a sea breeze	FINE LN

5.2 Order of Encoding. Encode echo systems in order of their importance, if apparent, otherwise in order of their extent, so that the most important and largest systems tend to appear first in the radar report.

5.3 Variability of Type and Intensity With Height. In general, report the type and intensity of precipitation occurring at the earth's surface. The following cases are to be treated as exceptions, or require special consideration:

(1) Elevated Layers: See ¶5.1.3.

(2) Evaporating Showers: Report the type and intensity of precipitation (in Column 3) based on radar indications at the level of maximum intensity and indicate the condition briefly in Column 10, e.g., "MOST PCPN NOT RCHG GND".

(3) Melting or Freezing Precipitation: When the character and reflectivity of echoes at radar observation levels cannot be expected to be representative of precipitation reaching the ground due to melting or freezing in intervening levels, determine and report the type of precipitation reaching the surface by means of meteorological analysis and surface reports and report the intensity as unknown.

5.4 Kind of Precipitation. It is not always practical to determine and report every kind of precipitation within an extensive echo system. Rather, the recorded radar observation should reflect the characteristic type, as defined in Paragraph 5.4.1,of each reported system, and, when deemed significant, an important secondary type.

5.4.1 Characteristic Type. The characteristic type of precipitation is defined, for convective systems, as the type of precipitation associated with the maximum observed intensity, and for non-convective systems as the type that is predominant in horizontal extent.

5.4.2 Thunderstorm. Based on reflectivity, vertical extent, and any other available information, designate echo systems believed to be associated with thunderstorms with the symbol "T" preceding the precipitation type symbol. Example: LN⊕ TRW/+ etc.

5.4.3 Precipitation Symbols. Select precipitation symbols from Table 5-2. Observational skills in evaluating reflectivity gradient, and vertical structure of the echoes, combined with meteorological judgment, are the best sources for determination of the characteristic type of precipitation for radar reports. Other sources of information such as synoptic charts, surface reports, telemetering, and visual observations, should also be considered.

If liquid and frozen precipitation are reported in the same system, record and report the liquid precipitation symbols first followed by the frozen precipitation symbols. For example, in the case of a thunderstorm producing heavy rain showers and hail, this portion of the report should read: TRW+A.

*Table 5-2. CHARACTERISTIC TYPE OF PRECIPITATION

Precipitation	Symbol
Rain	R
Snow	S
Showers	RW,SW,IPW
Drizzle	L
Ice Pellets	IP
Hail	A
Precipitation Aloft	R,S
Freezing Precipitation	ZR,ZL

5.5 Echo Intensity - Rainfall Rate. The relationship between the reflectivity of precipitation echoes and their rainfall rate while not precise can, nevertheless, be determined to a useful degree of accuracy. The radar term "echo intensity" and the meteorological term "rainfall rate" are sometimes used interchangeably. Determine the relationship of reflectivity, echo intensity, and rainfall rate, by means of calibration procedures, and conversion tables or graphs, furnished specifically for each type of radar (see B3.3 and B4.5).

5.5.1 Characteristic Intensity. Select one rainfall intensity category to characterize each reported echo system. For convective systems, select the maximum intensity. For other systems, give preference to that category that is predominant in horizontal extent. Use a remark to report intensities within a system that differ from the characteristic intensity to an important degree.

Example: "MOST SHWRS W OF GREENVILLE ARE LGT." "INCLS PATCHES OF R +."

Table 5-1. Characteristic type of precipitation

Precipitation	Symbol
Rain	R
Snow	S
Showers	RW, SW, IPW
Drizzle	L
Ice Pellets	IP
Hail	A
Precipitation Aloft	R, S
Freezing Precipitation	ZR, ZL

\# 5.5 Echo Intensity. Echo intensity will be reported directly after the precipitation type, using symbols from table 5-2. Determine echo intensity and its relationship to rainfall rate, using instructions provided with each radar. (See part B, ¶3.3 and 4.5.)

\# 5.5.1 Characteristic Intensity. Select one rainfall intensity category to characterize each reported echo type, except in those cases where the intensity is unknown. (See ¶5.5.2 and 5.5.3.)

For convective systems, select the maximum intensity found in the system. This is to indicate the known potential of cells in the system, and is used because convective cells can change their character and intensity very rapidly. In any field of convective echoes there will be some just developing, some at maturity, and some dying, but if the echo systems are selected and defined properly we can assume that any cell in a system of rain showers has the potential to reach the reported system intensity.

For stratiform systems, select that intensity that is predominant in horizontal extent. Such selection characterizes a stratiform system, because stratiform precipitation usually changes character and intensity much more slowly than convective type precipitation. A remark may be used to report intensities within a system that differ from the characteristic intensity but which do not constitute a separate echo system. Note that convective cells imbedded in stratiform precipitation should be reported as a separate system or as separately identified echoes within the system. (See ¶5.2.1 and 5.4.3.)

#Affected by Change No. 3.

* Table 5-2. Echo intensity - rainfall rate

Symbol	Estimated Precipitation	Echo Intensity	Theoretical rainfall rate in./hr.†
-	light	weak	<0.1
	moderate	moderate	0.1-0.5
+	heavy	strong	0.5-1.0
++	very heavy	very strong	1.0-2.0
X	intense	intense	2.0-5.0
XX	extreme	extreme	>5.0

†Based on the relationship $Z = 200R^{1.6}$

\# 5.5.2 Intensity Not Evaluated or Reported. Because of special problems involving reflectivity, do not evaluate or report an intensity for drizzle, hail, ice pellets, or snow. Use the precipitation symbols L, ZL, A, IP, IPW, or S without an intensity symbol. Do not use the symbol U. For a mixed system, consisting of a liquid characteristic type of precipitation and a frozen secondary type, a characteristic intensity is ascribed to the former but not the latter, as shown in these examples:

AREA4RW-SW/NC....etc.
LN8TRW+A/+....etc.

\# 5.5.3 Intensity Reported as Unknown:

a. Do not evaluate and report the intensity of echoes located farther than 125 nautical miles from the radar for WSR-57, AN/FPS-41, AN/FPS-68, AN/FPS-81, or AN/CPS-9 equipment; farther than 120 nautical miles from AN/FPS-77 equipment; and farther than 75 nautical miles for radars of less power and sensitivity such as the WSR-1 to WSR-4 series, the AN/APQ-13, the DECCA 41 and the AN/FPS-103. For echoes located outside these range limits, use the letter U after the precipitation type symbol to indicate that the intensity is unknown. The remarks section, column 10, MF7-60, may be used to report the estimated intensity of particularly significant echoes located beyond the limits specified. Example: APRNT TRW+ 251/181, etc.

#Affected by Change No. 3.
*Affected by Change No. 4.

5.5.2 Criteria for Reporting Intensity. Report the intensity of meteorological echoes in terms of the estimated precipitation intensity using the symbols in Table 5-3. This is based upon the generally accepted relationship $Z=200R^{1.6}$.

Table 5-3. ECHO INTENSITY - RAINFALL RATE

Symbol	Estimated Precipitation	Echo Intensity	Theoretical Rainfall Rate in/hr.	Reflectivity (Z) mm^6/m^3
--	Very Light	Very Weak	$<.01$	$< 2.3 \times 10$
-	Light	Weak	.01 - 0.1	$2.3 \times 10 - 9.4 \times 10^2$
	Moderate	Moderate	0.1 - 1.0	$9.4 \times 10^2 - 3.7 \times 10^4$
+	Heavy	Strong	1.0 - 5.0	$3.7 \times 10^4 - 5.0 \times 10^5$
++	Very Heavy	Very Strong	> 5.0	$> 5.0 \times 10^5$

*5.5.3 Reporting Intensity as Unknown.

a. Because of special problems involving reflectivity, do not ascribe an intensity to drizzle, hail, ice pellets, or snow. Use the letters L, A, IP, or S, without an intensity symbol to report any intensity of drizzle, hail, ice pellets, or snow.

b. Do not evaluate and report the intensity of echoes located further than 125 nautical miles from the radar, in the case of WSR-57, FPS-41, FPS-77V, FPS-68, FPS-81, CPS-9 and radars of similar sensitivity, or further than 75 nautical miles, in case of radars of lesser sensitivity such as the WSR-1 to WSR-4 series, APQ-13, and Decca 41. For echoes located outside these range limits, use the letter "U" after the precipitation type symbol to indicate that the intensity is unknown.

c. For echo systems located partly inside and partly outside the intensity reporting range limits stated above, assign the intensity determined within the valid range to the entire echo system if this intensity is believed to be reasonably representative. Otherwise, designate the intensity of the system as unknown.

d. Report the intensity of echoes as unknown whenever reflectivity measurements are doubtful due to a performance deficiency of the radar. Note that, in this case, the contraction ROBEPS (see Paragraph 9.3) will also be included in the report.

5.6 Intensity Trend

5.6.1 Period of Evaluation. The intensity trend will be observed and evaluated in terms of the net change in the characteristic intensity (see 5.5.1) during a specified period, which is one hour for lines and areas, and fifteen minutes for cells.

5.6.2 Criteria for Reporting Intensity Trend

a. Report the intensity trend as increasing (+), or decreasing (-), if, during the specified period, the net change in the characteristic intensity is approximately equal to, or exceeds, a full precipitation intensity category, or equivalent, e.g., from the threshold of "moderate" to the threshold of "heavy".

b. Report the intensity trend as "no change" (NC) if, during the specified period, the net change in the characteristic intensity is significantly less than a full precipitation intensity category.

c. Echo systems should be reported as a new development (NEW) if they originated during the period specified in ¶5.6.1

d. If the intensity trend is unknown or cannot be adequately evaluated for any reason, simply omit entry in Column 4. Note that the limitations discussed in ¶5.5.3 will also limit the reporting of the intensity trend. The "Remarks" section, Column 10, may be used to report the estimated intensity trend of echoes beyond range limits specified in ¶5.5.3b.

6. DIRECTION, DISTANCE, DIMENSIONS, OF ECHO SYSTEMS.

6.1 Evaluating Echo Configuration. Describe the location and the approximate horizontal shape and dimensions of related groups of echoes using direction-distance groups and width or diameter. Although the shape of echo systems should be smoothed and simplified for reporting purposes, select reported points so that reconstructed patterns will be similar and so that the true coverage and the coverage represented in the report are equal.

* Receiver gain settings will be increased and range normalization circuits (STC) will be turned off to enhance the detection of snow, drizzle, very light rain, and fine lines for reporting purposes; however, the horizontal coverage of other echoes should ordinarily be determined using standard receiver gain and STC.

6.2 Direction-Distance Groups. Record and report direction to the nearest whole degree relative to true north. Report true north as 360, ten degrees as 10 etc. Record and report distance to the nearest nautical mile if severe weather is involved or if special definition is needed. Generally, however, five mile increments of distance may be used in order to facilitate extraction of data from the radarscope. Separate the direction and distance figures with a slant in transmitted reports. Examples: 4/214, 73/6, 255/22.

6.3 Diameter or Width. When appropriate, record (in Col. 6) and report the average diameter or width of reported echo systems to the nearest nautical mile: D24, 5W, etc. Entries in Column 6 must refer to the echo pattern encoded in Column 3. When reporting secondary descriptive data, such as the average diameter of cells in a reported area, use the remarks section, Column 10. Example: AVG D3.

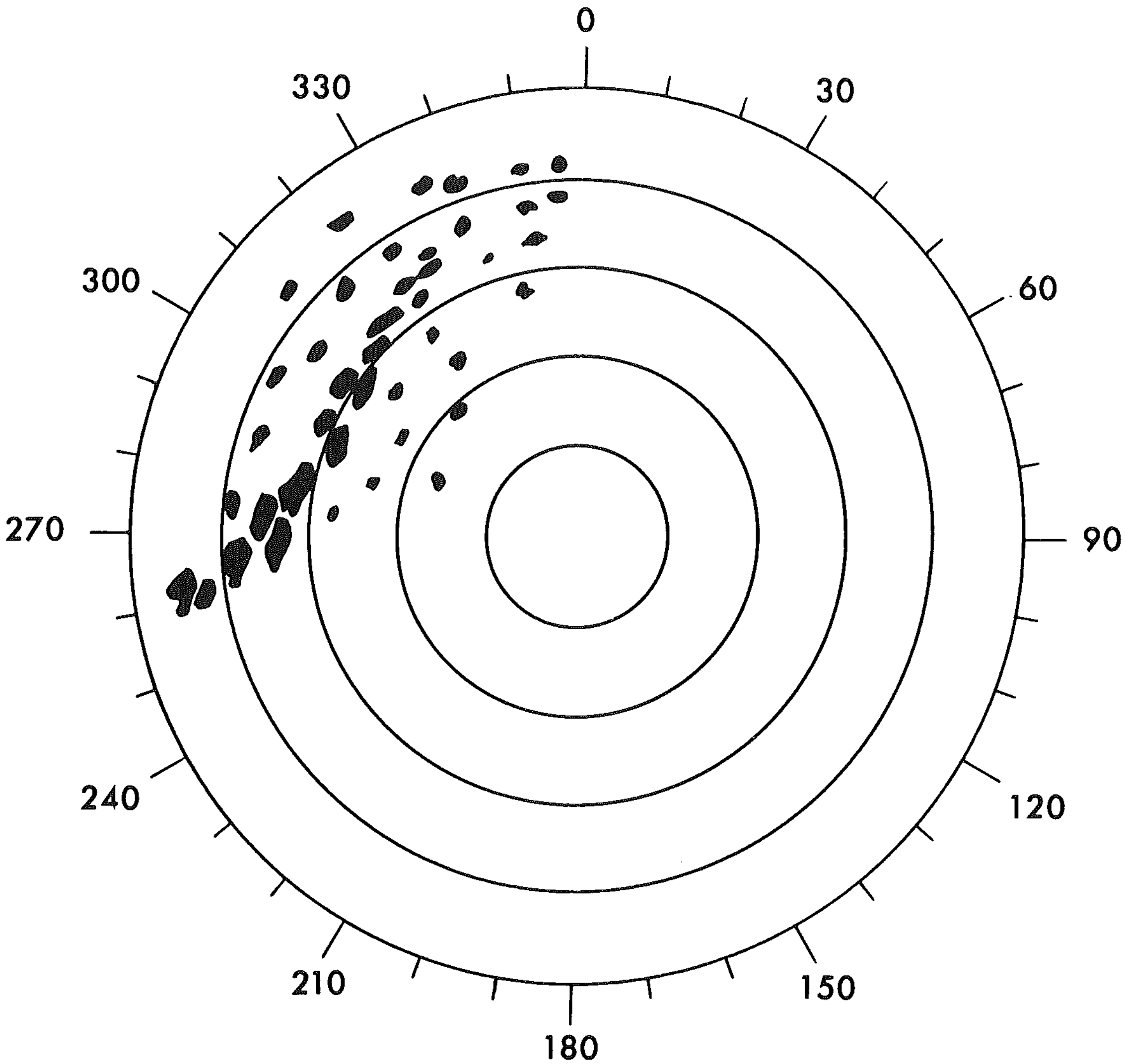
6.4 Circular Echo Systems. For echoes and echo areas that can be represented as circular, record the direction and distance to the center of the circle and the circle diameter.

6.5 Lines and Rectangular Area. For simple straight lines and rectangular areas, report the end points and average width. To represent curved lines and elongated curved areas, select additional points along the axis. To record lines of varying width omit entry in Column 6 and report the width by remarks in Column 10, e.g., 18W N END 4W S END. Report the points along the axis of a line or area from north to south.

6.6 Irregular Areas. Report irregular areas by encoding the directon and distance to salient points. Select the defining points so that a reconstructed figure will resemble the original area in both shape and area. Record and report the direction-distance groups in clockwise order beginning with the northern-most point.

*6.7 Cells. When a number of cells are to be reported and their distribution does not permit designating them as a line or area, enter, once only, the term CELLS (in Column 3) with their type, intensity, and trend of precipitation. Then enter the location, diameter, and top (if required), of each cell of the same intensity category in the allotted spaces of succeeding lines. If cells of another intensity category are observed, they will be reported similarly. (See 5.2.) To expedite the observational routine when such cells are numerous, the location, diameter, and top (if required) of individual cells may be entered on the observation form successively without regard to printed columns. Also, when numerous cells are being reported, it will be permissible to forgo measuring and reporting the top of each echo. As a general guideline in such a case, report about half of the top values including the tallest. A representative movement should be reported. Regardless of whether cell descriptions were entered successively or on searate lines, the teletype transmission should be in a continuing format, i.e., CELLS TRW/+ 273/58 D8 TOP 380 254/62 D7 239/88 D5 TOP 360 264/27 D1O CELLS 2530.

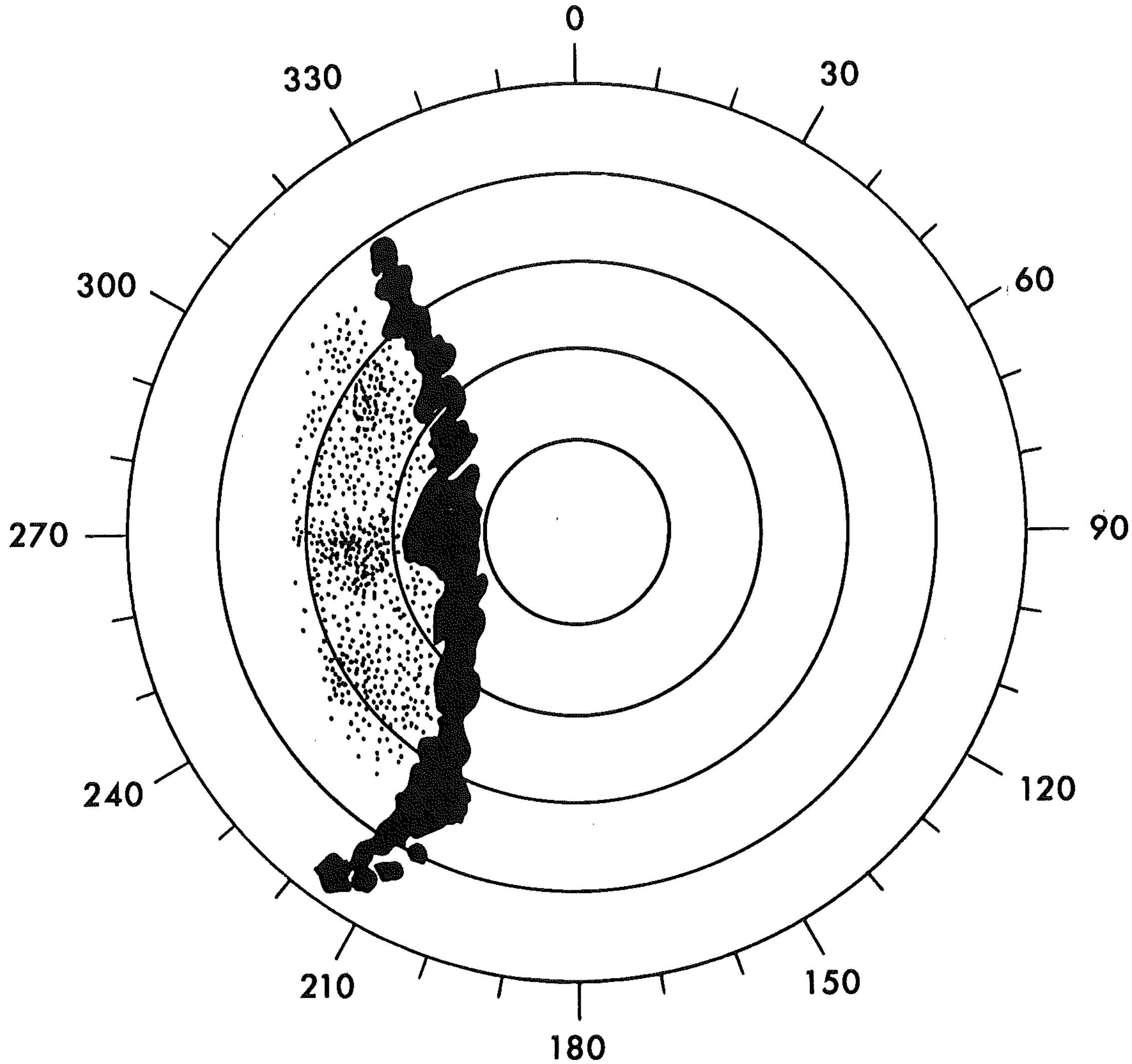
Figure 6-1. A Line of Thunderstorms Associated With a Shower Area.
(25 mile range marks)



This hypothetical radarscope display might be encoded in the RAREP below. The following paragraphs are especially pertinent in this situation: 5.1.2, 5.2, 6.1, and 8.3.

```
LN⦶TRW+/+ 333/85 269/85 261/110 10W 3012 CELLS 2815
  MAX TOP 380 AT 267/84 TOP 340 AT 278/82
AREA⦶RW/NC 357/110 289/40 272/100 321/115 2710 CELLS 2415
  MAX TOP 240 AT 316/95
```

Figure 6-2. A Mature Instability Line With a Trailing Band of Rain. (10 mile range markers)

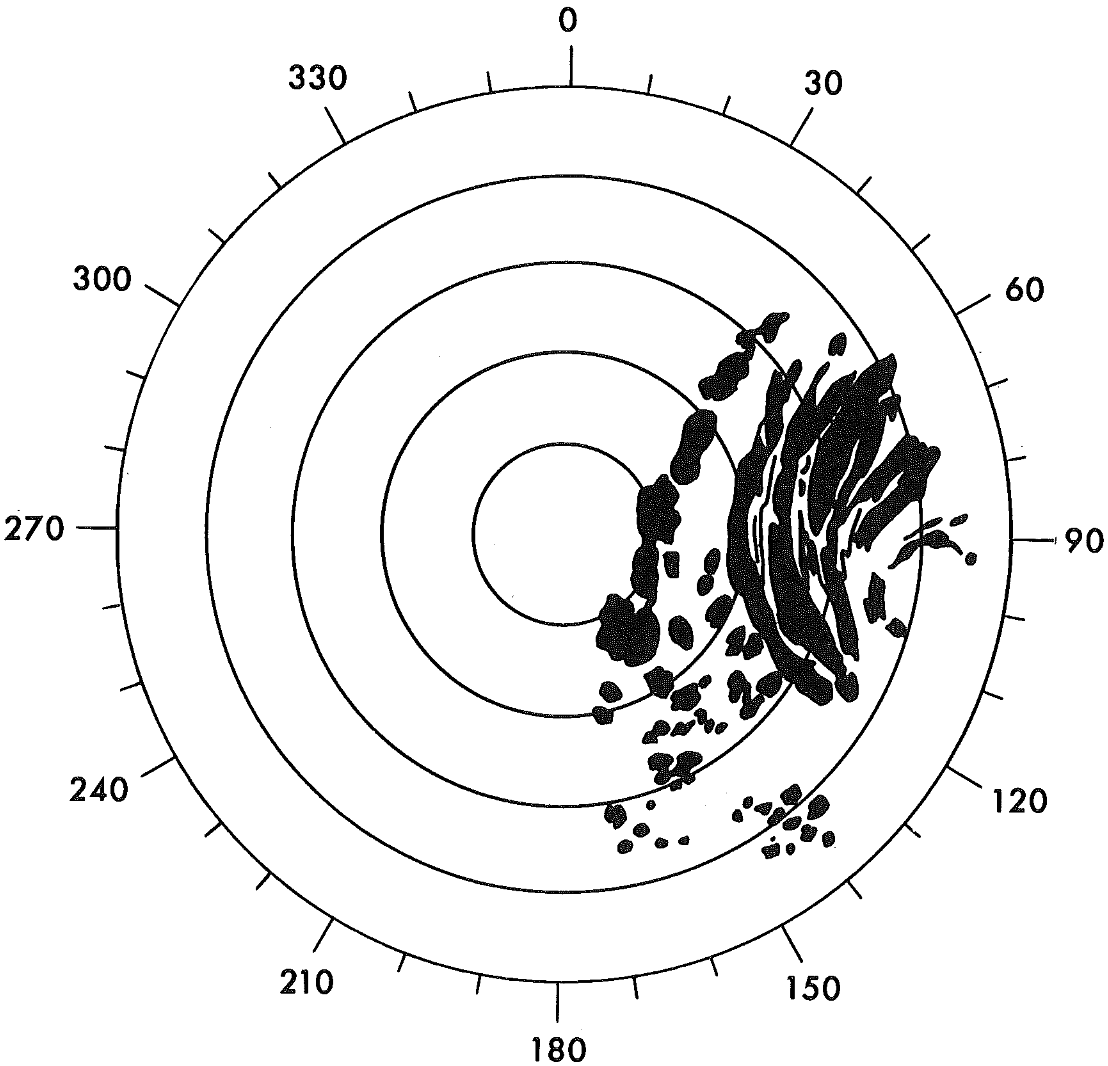


RAREP: (See ¶5.1.2, 5.4, 5.4.1, 5.4.3, 5.5.3a, and 8.3).

LN⊕TRW+A/NC 326/40 286/15 208/30 215/50 6W 2718 CELLS 2422
MAX TOP 420 AT 275/14 TOP 360 AT 208/32 HALF INCH HAIL
RPRTD AT 277/17
AREA⊕R-/+ 315/35 222/30 13W 2718 MAX TOP 280 AT 267/30

Note: The line is encoded as "solid" because there are no breaks or corridors (See Table 5-1).

Figure 6-3. Characteristic Pattern of Hurricane Echoes Showing Overshooting of Distant Echoes. (50 mile range markers)



RAREP: (See especially ¶5.5.3c, 6.1, 7.4, 11.3, and 11.6)

SPL 060342Z EYE 3211N 7604W D45 1610 FAIR FIX
SPRL BAND AREA⦶RW+/NC 50/200 93/230 124/190 99/80
  MAX TOP 320 AT 110/95
LN⦶TRW+/NC 44/170 73/55 153/80 20W MAX TOP 390 AT 149/67
AREA⦶RW/NC 92/75 125/145 167/180 167/100 CELLS 3440
  MAX TOP 250 AT 148/98
AREA⦶RWU 142/200 D45 CELLS 2835

7. MOVEMENT

7.1 Scale of Movement. Two scales of movement of radar echoes can be readily observed and measured and both have operational utility and should be reported. One is the movement of the entire system and the other is the movement of elements that make up the system. For example, a line may move from west to east while cells within the line are moving from southwest to northeast. Both types of movement are the resultant of translation and development vectors, but it is not intended that these vectors be distinguished (see B4.6).

7.2 Period of Evaluation. Determine movement data that is representative of a 15 minute interval for cells and small elements, and a one hour interval for areas and lines.

7.3 Units of Measurement and Reporting. Measure the direction from which echoes are moving, to the nearest ten degrees, relative to true north, and the speed of movement in knots. Record and report movement data using four-digit groups where the first two digits are direction in tens of degrees and the last two digits are speed in knots, use 36 for north, 01 for ten degrees, etc. Use 0000 to indicate no appreciable movement.

In transmitted reports, the first movement group will be understood to refer to the system reported in Column 3. Insert the word CELLS or ELEMENTS before the second movement group. If either category of movement is unknown, simply omit that group from the observation form and the transmitted report.

7.4 Determining the Movement of Cells and Areas. Derive the movement of isolated echoes and areas by considering successive positions of centroids or boundaries. Beware of erroneous movement that might seem real when the far side of an echo pattern is not observed due to over-shooting or attenuation (see B4.1).

7.5 Determining the Movement of Lines. Describe the movement of lines in terms of the component of motion perpendicular to the axis of the line rather than the total displacement. If the line is pivoting, or if a portion of the line is accelerating relative to the remainder, report the movement at two or more significant points.

8. ECHO TOPS

8.1 Principle of Evaluation. Echo height data are useful in assessing the degree of development of convective echoes, in severe weather analysis, in aircraft operations, and for other purposes. However, it is not feasible to maintain continuous observation of the vertical extent of echoes with a search radar. Operation of the radar in a height finding mode for excessive periods necessarily degrades other important functions. For this reason, observational operation should be aimed toward determining significant and characteristic height data by judicious sampling without excessive interruption of the normal mode of operation (see B4.3).

8.2 Reporting Echo Top Data. Determine the maximum height above mean sea level of each echo system and enter the corrected height to the nearest thousand feet, in hundreds of feet, in column 9. Since the term MAX TOP appears at the head of column 9 it should not be repeated on the observation form for each echo top reported. However, when observational data are extracted in message form, always include the term MAX TOP to identify the height portion of the encoded message.

*8.3 Reporting Echo Top Data for Large Systems. When reporting extensive echo systems, such as lines more than 50 miles in length or areas more than 50 miles in diameter, identify the echo associated with the maximum height by including the direction and distance to the center of the echo. In these cases, consideration should also be given to reporting additional tops. These additional entries should appear on the Radar Weather Observation Form in column 10 immediately following the maximum height value entered in column 9. Example (as transmitted on teletype):

MAX TOP 460 AT 311/33 TOP 430 AT 326/45 TOP 420 AT 335/86

*In the case of a stratiform system in which the same approximate maximum top value is observed at several locations, it will not be feasible to identify and report a unique maximum top.

8.4 Remarks Regarding Echo Top Data. Whenever feasible and appropriate, include a remark to indicate characteristic height values estimated from sample measurements. Example:

MOST TOPS BLO 250

8.5 Corrections Applicable to Echo Top Measurements. In addition to particular instrumental corrections that may be required, height data should be corrected for the following discrepancies before entry on the observation form:

a. height of the antenna

b. earth curvature

c. standard atmosphere refraction

d. half beamwidth (a negative factor).

8.6 Range Limitations for Echo Top Measurements. Because of decreasing elevation angles and increasing beam dimensions with distance, together with the unknown effect of variation in propagation paths, a maximum range limitation for reporting echo tops is necessary. Other difficulties, including the necessity of scanning very high tilt angles, preclude echo top measurement at very close range. The designed maximum range of the RHI of a particular type of radar is also, practically, a limiting factor. Echo tops should, therefore, be reported only within the following ranges:

CPS-9	5 to 100 Statute Miles
FPS-77V	5 to 120 Nautical Miles
WSR-57	5 to 125 Nautical Miles
FPS-41	5 to 100 Nautical Miles
WSR-1, 3, & 4	15 to 75 Nautical Miles

9. REMARKS, NOTES AND OPERATIONAL STATUS

9.1 Use of Remarks and Notes. Enter in Column 10 additional data that will supplement and amplify the encoded observation. Remarks to be transmitted should be brief, pertinent, and informative, and authorized contractions should be used. Authorized contractions are those specified in this manual and in the current edition of the FAA Air Traffic Service Handbook of Contractions (AT P 7340.1A). Remarks and notes not intended for transmission over primary teletypewriter channels should be enclosed in parentheses.

9.2 Photography Notes. At stations equipped with radarscope cameras, enter sufficient notes in Column 10 and in data blocks at the top of the observation form to constitute a complete record of photographic data acquisition. Such a record should include, if appropriate: camera on and off times, times of single exposures, change in exposure rate, change of film rolls, serial numbers of camera and magazine in use, and pertinent changes in radar and camera control settings including aperture.

9.3 Operational Status Contractions. The following contractions will be entered in Column 10 and transmitted separately, (see ¶12.2) or in combination with other observational data or remarks, when required to indicate the operational status of the radar.

PPINE — Equipment performance normal in PPI mode; no precipitation echoes observed; surveillance continuing.

PPIOM — Equipment inoperative or out of service for preventive maintenance. Follow the contraction with a date-time group (GMT) to indicate the estimated time when operation will be resumed.

PPINA — Observation omitted or not available for reasons other than those above. When feasible, follow the contraction with a date-time group (GMT) to indicate the estimated time when observations will again be available.

ROBEPS — Radar operating below performance standards. For use when a calibrated radar cannot be operated at the established standard performance level and when an uncalibrated type of radar is abnormally and seriously deficient in detection capability.

ARNO — A scope or A/R indicator inoperative.

RHINO — Radar cannot be operated in RHI mode. Height data not available.

9.4 Bright Band or Melting Level. When a bright band is observed in association with stratiform precipitation the zone of enhanced reflectivity should be examined on the RHI with controls set to provide optimum definition (see B4.4.2 & 4.4.3). The height of the top of the bright band may then be selected for reporting as the melting level with entries in Column 10 in the form of the following example: MLTLVL 75. The height reported will be in hundreds of feet (MSL) after the following corrections have been applied:

a. height of the antenna

b. earth curvature

c. standard atmosphere refraction

d. half beamwidth (a negative factor).

10. SEVERE WEATHER ECHOES

10.1 Reporting Especially Significant Echoes. Whether occurring separately or within a reported line or area, echoes potentially associated with severe weather should be reported separately within regular reports and as the content of special observations (see ¶12.3.1) in as much detail as practicable. The definition of echoes can usually be improved by reducing receiver gain or using the attenuator control. Intense echoes should always be analyzed carefully for hooks, holes or appendages that may be related to severe weather. Along with radar detection and analysis, all sources should be used to ascertain and report the type of weather that is occurring with severe weather echoes.

In particular, the following especially significant echoes should be reported in both regular and special observations:

a. Report individually all echoes of "EXTREME" intensity.

b. Report individually echoes of "VERY STRONG" or "INTENSE" intensity if located in or near a severe weather forecast area.

c. Report individually echoes whose tops are within 5,000 feet of a known tropopause height, exceed the tropopause, equal or exceed 50,000 feet. An exception can be made for echoes that are clearly not associated with severe weather; for example, rain or snow producing echoes associated with a low, polar-type tropopause.

d. Report individually echoes having features (such as hooks, holes, and appendages) which are characteristic of severe weather.

e. Report individually intense echoes whose projected paths intersect.

10.2 Line Echo Wave Pattern (LEWP). If an echo system contains a LEWP, report the complete system first and then the LEWP identified by the contractions "INCLS LEWP" and a sufficient number of points (usually four) along the axis of the line to delineate the wave pattern. On the Radar Weather Observations Form the LEWP should be reported on a separate line immediately following the complete system. It is usually necessary to use the attenuator control or reduce receiver gain in order to give satisfactory definition to the LEWP.

11.0 HURRICANE ECHOES

11.1 Operations During Tropical Storms and Hurricanes. Radar observations serve additional purposes and have special importance during tropical storms and hurricanes. Radar reports are an important input into hurricane forecasting and warning centers and also contribute to local warnings and amplifying bulletins. To meet all of these requirements, an expanded and continuous radar operations program is usually required.

11.2 Scheduled Hourly Observations. Transmit a complete radar report each hour at scheduled observation times (usually H + 45) over the designated communication channel. Include, if observable, the eye or center data, spiral band areas, and the rain shield.

11.3 Special Observations. Designate a s a special ("SPL") observation and include the date and time of observation (GMT) in the transmission of any radar report that contains an eye or center position.

11.4 Intermediate Special Observations. At H + 15 report the eye or center position together with any identification and qualifying terminology such as PSBL, 15 DEG SPRL OVERLAY EYE, GOOD FIX, etc., but do not include descriptive data such as diameter, shape, or movement. Example: MIAC SPL 101614Z PSBL CNTR 2817N 7835W.

11.5 Definition of Eye or Center. Derive the eye or center position from a continuous and logical sequence of observations. Ideally, the radar-derived eye is readily apparent as an echo-free area, circular or oval in shape, contained within the wall cloud. It is the geometric center of this echo-free area that will be reported as the eye location. If the wall cloud is not completely closed, it is still usually possible to derive an eye location with a high degree of confidence by sketching the smallest circle or oval that can be superimposed on the inner edge of the existing portion of the wall cloud. If the wall cloud is not well-developed but a center of circulation is identifiable then this feature should be observed and reported similarly to an eye.

11.6 Terminology. If the central region of a storm is defined by an identifiable wall cloud, report the fix as an "EYE". If a center of circulation is recognizable but not well-defined by a wall cloud, report the fix as a "CNTR". If the eye or center is only occasionally recognizable, or there is some other reason to suspect an uncertain central organization, the fix should be designated "PSBL EYE" or "PSBL CNTR".

Include a remark with eye fixes to indicate the degree of confidence in the fix. Qualifying remarks will not, ordinarily, be applied to center fixes. The following guidelines are meant to be suggestive rather than absolute: If the wall cloud is closed, or almost closed, and the resultant eye is symmetrical, include as a remark the phrase "GOOD FIX" in all observations. If the derived fix is believed to be useful although ambiguous due to lack of completeness of the wall cloud, e.g., less than 50%, or because of lack of symmetry of the eye configuration, include the remark "POOR FIX". The phrase "FAIR FIX" will be used to express an intermediate degree of confidence.

11.7 Use of Spiral Band Overlays. Spiral band overlays may be used when the center of the storm is over water to estimate the location of the eye or center whenever it is indistinct, out of range, or whenever the radar beam is overshooting the center of the storm. Normally at least 90 and preferably 180 degrees arc of a spiral band must be present on the radarscope to assure a usefully accurate estimate of the storm's center position. Standard overlays are available with 10, 15, and 20 degree crossing angles. Since the crossing angle of a given band may increase from near zero degrees at the eye to more than twenty degrees at distances over one hundred miles from the center, the most satisfactory results can be expected by use of the spiral band overlay which best fits the intermediate portions of the band. Control settings should be carefully adjusted to enhance the definition of the spiral bands. Depending on the particular type of radar, it may be more convenient to trace the centers of the spiral bands on a map-type overlay before fitting the spiral band overlay. If the eye position is determined principally by means of a spiral band overlay, the report should indicate this. For example: 15 DEG SPRL OVERLAY EYE 2533N 7046W.

11.8 Encoding Location of Eye or Center. Record and report coordinate positions of the eye or center to the nearest minute of latitude and longitude by means of unpunctuated five-character groups. A position of 28° 35' north, 78° 17' west, should appear on observation forms and teletype transmissions as 2835N 7817W. Omit the hundreds digit if necessary. For example, a position of 32° 34' north, 118° 16' west, should be encoded as 3234N 1816W. Record, but do not transmit, azimuth and range data from which coordinate positions are derived.

11.9 Movement of Eye or Center. Determine the speed and direction of movement of an eye or center from the change of position measured over the previous one-hour interval. Report eye or center movement by using a four-digit group. Two digits will represent the hundreds and tens value of the direction, to the nearest ten degrees, from which the eye or center is moving. The third and fourth digits will represent the speed in knots. For example, if the eye movement were determined to be from 208 degrees at 7 knots, the movement group would be coded as 2107.

12. OBSERVATION SCHEDULES AND SPECIAL OBSERVATIONS

\# 12.1 Scheduled Hourly Observations. When reportable meteorological echoes (see ¶3.1) are observed, a complete radar observation should be encoded just prior to the hourly scheduled teletypewriter collective at H + 40. As an exception, operating agencies may designate a different schedule in particular cases where communications requirements demand. Transmission of the encoded observation should be accomplished in accordance with appropriate procedures and schedules furnished by the operating agency for particular circuits.

\# 12.2 Transmission of Operational Status Reports. When a scheduled hourly radar observation is not available owing to absence of meteorological echoes, or inoperative equipment, log and transmit the operational status report in lieu of the next scheduled observation and subsequently at 0240, 0540, 0840, 1140, 1440, 1740, 2040, 2340 GMT . (See ¶9.3.)

\# 12.3 Special Observations. Unlike scheduled hourly observations, special observations will be encoded to include only the echoes of special interest. The selected echoes should be reported in rather complete detail including remarks. Special observations may be encoded and transmitted immediately or in intermediate collectives at H + 10. Identify special observations and regular observations meeting the criteria for special observations by writing the contraction "SPL" in the left margin of MF7-60, and transmitting this contraction immediately after the time groups. (See ¶4.2.)

\# 12.3.1 Criteria for Special Observations. Encode and transmit an abbreviated special observation immediately when echoes of the following categories are first observed and at H + 10 as long as they persist:

(1) Echoes of "EXTREME" intensity.

(2) Echoes of "VERY STRONG" or "INTENSE" intensity located in or near a severe weather forecast area.

(3) Convective echoes having features (such as hooks, holes, and appendages) which are characteristic of severe weather.*

(4) Convective echoes whose projected paths intersect.*

*Include descriptive remarks to indicate the reason for special interest.

#Affected by Change No. 3.

(5) Convective echoes, with severe weather potential, whose tops are within 5,000 feet of the tropopause, exceed the tropopause, equal or exceed 50,000 feet MSL.*

(6) Convective echoes with intensity greater than "STRONG" that persist at the same location for an hour or more.*

(7) Line echo wave pattern - LEWP. (See ¶10.2 and part B, ¶5.1.2.3.1.)

12.3.2 Tornadoes and Severe Thunderstorms. Immediately after taking any required warning action, encode and transmit an abbreviated special observation upon receiving any information, whether verified or not, indicating that a tornado or severe thunderstorm may be occurring or might have occurred during the past hour within radar range. Further special observations should be recorded and transmitted if additional significant information pertaining to the possibility of a tornado or severe thunderstorm can be obtained through observation or inquiry.

12.3.3 Aircraft in Distress. Encode and transmit a complete special radar observation immediately upon receiving any information, whether verified or not, indicating that an aircraft may be in distress within the maximum range of the radar.

12.3.4 Aircraft Accident. Encode, but do not transmit, a complete special radar observation immediately upon receiving any information, whether verified or not, indicating that an aircraft accident may have occurred during the past 30 minutes within range of the radar.

12.3.5 Eye or Center of Tropical Storms and Hurricanes. Transmit the eye or center position of tropical storms and hurricanes at H + 10 by means of a special observation and designate regular observations containing an eye or center position as a special (SPL) observation. (See ¶11.3 and 11.4.)

12.3.6 Flash Floods. Encode and transmit an abbreviated special observation immediately upon receiving any information, whether verified or not, that a flash flood may be occurring in the vicinity of observed echoes. Special reports should be prepared at H + 10 and H + 40 as long as echoes are observed over the area of reported flooding.

*Include descriptive remarks to indicate the reason for special interest.

#Affected by Change No. 3.

12.4 Transfer of Network Responsibilities. Where alternate stations have been designated, the following procedures will be followed whenever a network station is not able to make observations and transmit reports. (See ¶9.3).

(1) The primary station will notify the alternate station expeditiously.

(2) The primary station will transmit an operational status contraction (PPIOM or PPINA) followed by a date-time group indicating when reports are expected to become available again and the call letters of the alternate station. Example: MXF PPIOM 251240Z ALTN SEM. If possible, such a report will be transmitted, along with any other available observational data, in the last hourly scheduled teletypewriter collective before going out of service.

(3) The alternate station will append a remark to all reports transmitted in lieu of primary station reports to indicate the circumstances, e.g., SEM . . . MXF PPIOM 251240Z.

(4) The primary station will transmit status reports in accordance with ¶9.3.

(5) An alternate station having an outage while serving in lieu of a primary network station will transmit an appropriate operational status report.

(6) A primary network station will be responsible for coordination with the alternate station including updating estimates of the time of service resumption and establishing the exact time of resumption of network responsibilities.

13. OBSERVING AND REPORTING PROCEDURES IN SUPPORT OF REMOTE DISPLAYS

13.1 General Information and Policy. Network radars will often be used to furnish data to remote stations in the form of radarscope displays and annotations. A radar remoting system such as the WBRR-68 is a relatively economical means for extending radar service to locations within about 75 n. mi. of the radar. Government agencies, private meteorologists, TV stations, etc. can be provided with a near real-time PPI display and expert interpretation in the form of annotated remarks. Occasional telephone consultations will be possible between government offices with remote displays and the radar site.

The remote stations will be dependent on the radar operating staff for annotations and other supporting services. Proper installation and maintenance of the equipment is a necessary but insufficient condition to provide satisfactory service. When a radar remoting system is installed, the radar observer can no longer operate the radar when and how he chooses, since operation of the radar directly affects the output of the remoting system. For example, interruption of the PPI scanning mode of the radar automatically causes the WBRR system to go into storage mode; obviously PPI scan interruptions either too frequent or too long in time will cause partial or old data to be presented at the receiver sites. The radar observer should be constantly aware of the other offices relying on a continuous flow of PPI data, and should make observations with as few PPI scan interruptions as possible. The other aspects of satisfactory service involve making timely and accurate echo interpretations and answering the telephone quickly when calls are received from the remote stations. The agency operating the radar should ensure that personnel with adequate training in radarscope interpretation are immediately available when weather echo information is being relayed over the remoting system. Local agreements should be executed by the agencies involved, following the policy guidelines described herein.

*13.2 Frequency of Operations. A radarscope display with appropriate annotations should be transmitted continuously whenever meteorological echoes are detected or expected. At other times, the remoting equipment should normally be used to transmit a suitable display indicating the operational status of the radar even though the radar may be off or in standby mode.

13.3 Operational Procedure

13.3.1 Radar Operation

a. Operate the radar in normal PPI mode as much as possible.

b. When making RAREPS use the mechanical cursor on the PPI, if available, to determine azimuths to echoes, and estimate ranges to echoes to the nearest five (5) miles. For severe weather echoes, however, the antenna may be stopped in order to determine the range to the nearest mile using the range strobe.

c. During periods when severe local storms are imminent or occurring, an additional radar man is probably necessary if maximum utility is to be obtained from the equipment.

d. When using WBRR- type remoting equipment, as far as possible, wait until the transmitter has completed a scan before interrupting antenna rotation. When normal PPI rotation is resumed, continue for at least 3 complete frames if at all possible (about 5 minutes) and never less than 1 frame. (After a period of storage, the old frame is erased before the new frame is "written in." Three frames are required before a normal picture is displayed by the receiver).

13.3.2 <u>Data Insertion Device (DID). (WBRR- Type Equipment)</u>

a. Opening the access door, necessary for updating the DID, automatically causes the WBRR to go into storage mode. Carry out the updating as quickly as possible. Make certain the access door is properly closed to insure continued transmission.

*b. When meteorological echoes are being transmitted, place annotations on the data insertion device (DID) at regularly scheduled hourly periods - more often, if required - to describe changes in echo parameters that are not readily observable on the remoted display. Time of up-dating should be indicated.

c. Write annotated remarks "in the clear," i.e., not over echoes, and if possible, upstream from echoes rather than in their path. Avoid interference with map data.

d. Use standard RAREP terminology and definitions (see Section 5), except as indicated below. The following items will generally be included in the annotated remarks:

	Item	Example
1.	Time (According to general usage)	1100 EDT
2.	Precipitation type	RW
3.	Intensity	-
4.	Intensity trend	/+
5.	Movement of area or line	2420
6.	Movement of cells	C1925
7.	Echo height	MAX TOP 200

e. For precipitation aloft, indicate tops and bases, for example:

LYR $\frac{150}{70}$

f. Identify separately all echoes in the strong or very strong intensity category, or those associated with severe local storms, using arrows where necessary. Specifically, all echoes producing reflectivity values of $Z = 10^5 mm^6/m^3$ or greater, or echoes with tops reaching 50,000 feet or greater, will be labled separately. Separate the Z value from the height value with a slash. For example, if $Z = 10^{5.4}$ and maximum top is 52,000 feet, the label would be 5.4/520. (This information should be updated more than twice per hour).

*g. Indicate nonprecipitation echoes by an annotation that will be easily understood by viewers, e.g., "NON PRECIP," "WIND SHIFT LINE."

*h. When appropriate, indicate the radar status, e.g., "NO ECHOES," or "RADAR OFF FOR MAINTENANCE UNTIL 1400 CST."

13.3.3 <u>Verbal Relay of Information to Other Government Offices.</u> Provide additional interpretation of echoes over the telephone. Telephone calls are initiated at either the radar or remote government office. The goal should be to provide the optimum amount of information by graphic means in order to minimize such calls.

Weather Radar Manual

(WBAN)

PART B

August 1967

U.S. DEPARTMENT OF COMMERCE ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

U.S. DEPARTMENT OF THE AIR FORCE Air Weather Service

U.S. DEPARTMENT OF THE NAVY Naval Weather Service

Weather Radar Manual

(WBAN)

PART B

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Chapter 1

RADAR FUNDAMENTALS

1.1 INTRODUCTION

For more than 100 years meteorologists have been depicting the current state of the weather as a basis for prediction. For the most part the depiction is made up from point observations. Over the years the network of these observations has been greatly expanded in both time and space and is approaching the limits of feasibility from an economic and communications standpoint. Even by taking full advantage of these observations and compiling a weather chart each hour, it would still not be possible to depict all the relevant detail of the mesoscale weather pattern which can be utilized in precision short range forecasts. This is where weather radar steps in and supplies a detailed, continually up-dated presentation of precipitation. The radar can be viewed as an infinite network of observing stations instantly communicating multi-dimensional observations to the user in a readily interpreted form. Weather radars in the S, C and X bands depict mainly the precipitation field. But, other parameters of interest in local forecasting, namely clouds and obstructions to vision are rather closely related to precipitation, at least in a qualitative manner. On the other hand, the radar data do not replace conventional observations but supplement them. For optimum results the user must keep himself well briefed on synoptic and mesoscale events to which the depicted radar data are closely related.

1.2 GENERAL

RADAR is coined from the expression RAdio Detection And Ranging. Most radars used for weather detection purposes are pulse radars: electromagnetic or radio energy is emitted in the form of pulses of about a microsecond in duration. The radar antenna transmits this energy in the form of a directional beam a few degrees in width (Fig. 1-1). Targets which intercept this energy return a small portion of the energy to the antenna. In the time interval between pulses, the returned signal is detected and amplified in the radar receiver and displayed on various display scopes (cathode ray tubes). The time duration between the emitted and received signal is a measure of the range of the target. The antenna may be rotated or elevated to determine the azimuth and height of a target.

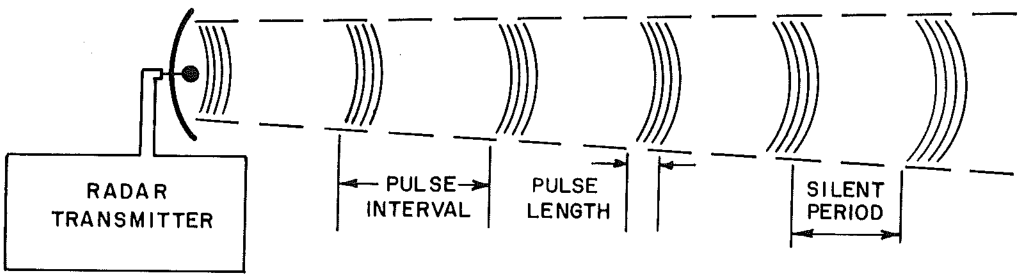

Figure 1-1. Representation of a Pulse Radar Beam

Radars may be coherent or non-coherent. In a coherent radar, the phase of the transmitted signal is preserved in a reference signal for comparison with the received signal. Changes of phase in the return signal are proportional to a Doppler frequency shift associated with moving targets. Hence the radial component of the velocity of a moving target may be determined with a coherent radar. Pulse Doppler radars now used in research are coherent. This type of system has possible applications in detecting and measuring the strong winds associated with tornadoes by determining the speed of particles in the funnel cloud.[1] Pulse Doppler radars have also been used experimentally to measure wind speeds and particle fall velocity in widespread precipitation.[2]

In a non-coherent radar there is no reference signal and only the range and direction of a target may be determined. However, the signal fluctuations on a non-coherent radar are related to the Doppler frequency spectrum and so contain information pertaining to the motions of the targets which may be analyzed with special equipment. Most weather radars in operational use today are non-coherent; these include the AN/FPS-77, the WSR-57, the AN/CPS-9 and the AN/TPQ-11.

In all systems where electromagnetic energy is radiated, some of the energy is attenuated in its passage through the atmosphere. The degree of attenuation is dependent on many factors such as frequency of emission, water content in the atmosphere, etc., and it is the measured relative variations of some of these factors that provide the references for analysis of weather by radar.

1.3 THE RADAR SET

All pulsed radar sets regardless of size or purpose have the same major components (see Fig. 1-2), although in construction there are many different arrangements.

1.3.1 Transmitter

The block diagram of Figure 1-2 illustrates the operation of a typical pulse radar system. In the radar system the timer triggers the modulator to send a high power, high voltage pulse to the magnetron, the transmitting tube. The magnetron oscillates at the radio frequency for which it was designed and sends an RF pulse along the transmission line past the ATR (anti-transmit receive) and TR (transmit receive) tubes to the antenna. During transmission the gas in these tubes ionizes and effectively short circuits the receiver line in order to prevent damage to the sensitive receiver equipment. Between pulses the TR tube connects the receiver to the antenna and the ATR tube disconnects the magnetron in order to prevent loss of any part of the received signal. Some radars, such as the AN/TPQ-11, use separate antennas for transmitting and receiving, and in so doing eliminate the need for TR and ATR tubes.

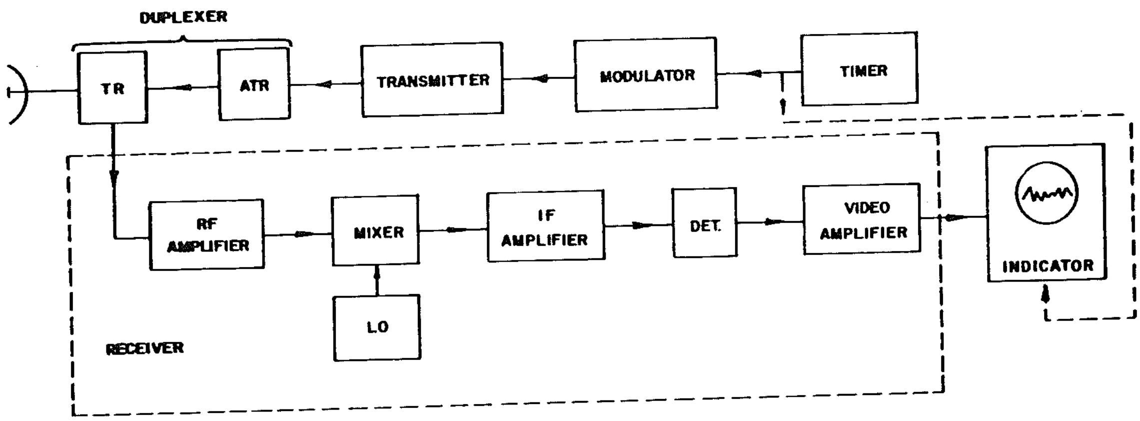

Figure 1-2. Block Diagram of a Pulse Radar System [5]

1.3.2 Receiver

The return signal scattered back by the target is received by the same antenna and switched into the receiver where the mixer and the local oscillator (LO) transform the RF signal to intermediate frequency (IF). After amplification, the IF pulse signal is converted to video by the detector and amplified by the video amplifier for presentation on an indicator. Coincident timing pulses from the timer are also transmitted to the indicator to initiate range sweeps.

1.3.2.1 Noise

Noise is always present in a receiver due to the random motion of the electrons which occur in any conductor at a temperature greater than absolute zero. The power magnitude of this thermal or Johnson noise is given by [5]

$$N = kTB$$

where k = Boltzmann's constant

T is the absolute temperature taken to be 290°K for reference purposes

B is the bandwidth

The product of kT is 4×10^{-21} watts/cps of bandwidth. The bandwidth is defined as the separation in cycles per second between the points where the frequency response (of the IF amplifier in most receivers) is reduced by 0.707 (3 db in power) from its maximum value. (See Section 3.2.) The value of the receiver bandwidth can be measured and may be considered as a known characteristic of a radar.

Thermal noise represents the minimum noise inherent in any receiver. In practical receivers the noise power is considerably greater than that arising from thermal or Johnson noise alone, and is due to random electron flow arising in other mechanisms, such as input circuits, mixers, or conversion circuits. The minimum detectable signal is the product of the total noise and the minimum signal-to-noise ratio. In most cases the signal-to-noise ratio, for minimum signal detection, is assumed as one (1). Therefore, minimum detectable signals can be defined as the product of the noise figure (F) and thermal noise or total noise.

In addition to receiver or internal noise there is environmental or external noise. There is also cosmic or galactic noise, which is a continuous background of radiation from outer space. The cosmic noise is greatest in the direction of our own galaxy and the sun. In general the external noise is relatively small compared to the internal noise in the microwave receivers. There is also atmospheric noise produced by lightning in thunderstorms which are always present somewhere on the earth. Lightning within range of the radar is occasionally detected (see Section 3.7).

1.3.3 Antenna

For weather radar the antenna is in the shape of a paraboloid which transmits the radiated energy into space, and receives the energy of the echo signal. In the early days a radar antenna consisted of a simple half wave dipole element placed at the focus of the paraboloid. Present weather radars generally use a waveguide horn which has considerably greater directability and better paraboloid illumination control.

The antenna concentrates the energy into a shaped beam pointed in the desired direction. A typical radiation pattern from a paraboloid antenna is shown in Figure 1-3. After the primary lobe, which contains most of the energy, is the first side lobe which typically occurs at an angle of about two beam widths off the axis and in which the energy is diminished by about 30 db (or 10^3). Other side lobes are generally minor compared to the first one.

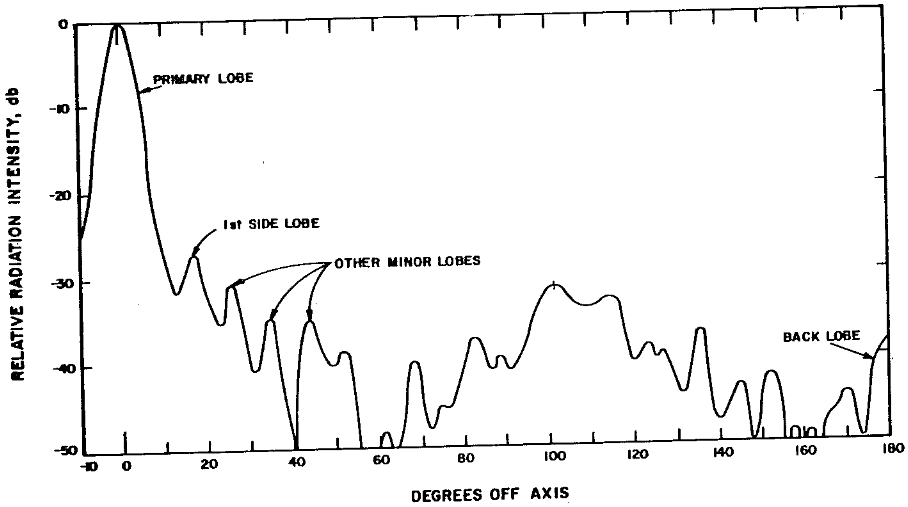

Figure 1-3. Typical One-Half Radiation Pattern for a Radar Having a Paraboloid Antenna [5]

Although the effect of side lobes may generally be neglected, they are important particularly in quantitative radar techniques. In measuring the echo intensity from storms one of the side lobes may be detecting a very strong echo away from the echo being measured and thus contribute appreciably to the energy received. In addition, side lobes occasionally produce "spikes" above thunderstorm echoes causing spurious echo tops (Section 4.3). Electromagnetic radiation is characterized by an electric field and a magnetic field, which are always perpendicular to each other and to the direction of the electric field of the radiation. Most radars are linearly polarized either horizontally or vertically. For linear polarization the electric field may be interpreted as a sinusoidal wave vibrating in one plane. The antenna may also be polarized circularly or elliptically. Circular polarization may be interpreted to consist of a combination of two waves of equal amplitude, one vibrating horizontally the other vertically. In elliptical polarization the amplitudes are unequal.

From aerodynamic considerations, snowflakes or large drops tend to fall with their maximum areas horizontal. From this viewpoint horizontal polarization would be favored for maximum echo return. However, the effect has been found to be relatively minor, so that either horizontal or vertical polarization is suitable for storm detection.

The reflectivity of precipitation for circularly polarized radiation is lower than that for linearly polarized radiation by about 20 db for rain, 15 db for snow and about 10 db for melting snow. This property allows radars using circularly polarized radiation to detect targets, such as aircraft, in rainstorms.

Because antennas may often be subjected to severe weather, such as icing, high winds and temperature extremes, they are usually enclosed in a shelter called a radome. The radome must be strong to provide protection but also must not attenuate or distort the energy to and from the antenna. Wet radomes during heavy rain are known to cause some attenuation and distortion, particularly at 3 cm or less, which may have an influence on quantitative measurements.

1.3.4 Indicators

Several types of indicators are used in radar sets. Most of the indicators consist of a cathode ray tube (CRT) similar to that used in television sets. A CRT consists of an electron gun, a magnetic or electrostatic deflector and a display screen. The electron stream from a hot cathode is focused on a screen coated with a two layer deposit, one layer which fluoresces for a short duration (0.1 seconds or less), and the other, nearer the operator, phosphoresces for a duration of seconds.

The most important indicator in storm detection is the PPI (plan position indicator) which is a polar coordinate plot of azimuth vs. distance. Most weather radars utilize a CRT with a magnetic coil which rotates in synchronization with the antenna and deflects the electron beam according to the location of the radar pulse in space; by this means the precipitation areas are "mapped" on the scope. Fixed range markers, which generate concentric rings as the PPI sweep is rotated, can be switched on the scope as desired.

Another indicator, the range height indicator (RHI), gives a rectangular plot of horizontal range vs height and enables one to see a vertical cross section of precipitation in any direction. Height markers at convenient height intervals, such as 5,000 or 10,000 ft., may be shown on the screen.

Both the PPI and RHI are intensity modulated CRT's which are normally dark in the absence of a target. They have a relatively small range of brightness with a dynamic range of 10 db or less and hence, cannot in general be used to gage storm intensity when used at a fixed gain setting. A different type of indicator, which is used in the AN/FPS-77 radar, is the "DARK TRACE TUBE." This is a storage type of display which, when supplied with target information, holds the target information displayed for an indefinite period. Provisions are included to erase this stored data when it is no longer desired. In this tube the targets appear as magenta colored spots against a grey-white background and, of themselves emit no light after they are stored. Consequently, these displays can be viewed in well lighted environments but require artificial illumination in a non-lighted environment. Their application in weather radars to date has been for PPI displays only. As in the case of normal CRT's the range of signal intensity displayed is 10 db or less.

A third type of indicator, the A-scope, is an amplitude modulated CRT that provides a rectangular plot of range vs relative signal intensity from the target. The gain control regulates the magnitude of signal intensity on the scope. A switch converts the A-scope into an R-scope, which is a magnified portion of a selected range interval on the A-scope. The A-R scope is used to determine the character of the signal received. An operator can easily distinguish the characteristic fluctuations of incoherent broad precipitation echoes from the narrow, relatively stationary coherent echoes from fixed targets. The first several hundred feet equivalent range on the A-scope is the saturated signal from the main pulse, which leaks through the reciever to the indicator. Beyond the main pulse are the fluctuating noise signals inherent in the receiver and received from space. In order to be detected on any scope the signals from outside targets must be greater than this noise level. The R-scope is occasionally useful in magnifying distant echoes of relatively weak intensity.

1.4 RADAR DETECTION

Radar detection depends on the energy scattered or reflected back to the radar receiver by objects which intercept this energy. This is similar to the detection of objects by visual means, e.g., our own eyes, where we depend on the light energy emitted by the sun and scattered back or reflected by objects that we "see." "Target" is the general term for objects seen or detected by the radar. In radar meteorology the term "target" refers to anything in the atmosphere or its boundaries which returns to the radar a detectable amount of energy which will then appear as a signal or an echo on the various display scopes and which can be distinguished from the ever-present noise (see Section 1.3.2). Targets of a weather radar may properly consist of raindrops, hail, snow crystals and snowflakes, cloud droplets, ice cloud particles or various assortments of these as they are found in natural precipitation or clouds. In addition to these meteorologically significant phenomena, solid objects such as land surfaces, buildings and trees, the surfaces of lakes or oceans, birds, insects, and possibly invisible regions in the atmosphere where strong gradients of temperature and humidity exist, may become radar targets and produce echoes of varying degrees of usefulness or nuisance.

The targets with which the operator will be most often concerned will be those resulting from precipitation. From the onset it is of extreme importance for the radar user to realize the great prejudice of the radar toward the larger size particles. Thus the radar "sees" precipitation particles in assorted sizes in such a way that the importance of the largest particles is vastly exaggerated while the smallest ones are virtually neglected. For instance, if raindrop "A" has ten times the diameter of raindrop "B", the signal or echo sent back to the radar receiver from "A" will be a million times stronger than that from "B", other factors being equal. In some respects this is fortunate because the more hazardous weather in terms of turbulence, high, gusty and even destructive winds and hail is associated with concentrations of large particles and hence intense echoes. Further consideration of the radar reflectivity problem is given in Chapter 3.

1.5 RADAR FREQUENCY BANDS

Modern radars operate in a portion of the microwave region of the electromagnetic or radio spectrum from less than 1 cm to 23 cm in wavelength or about 50,000 to 1,300 mc/sec in frequency. Most operational weather radars function at either 10, 5 or 3 cm although some valuable weather information is obtained from 20 cm radars, and for cloud detection, one resorts to wavelengths as short as 0.86 cm. Other factors being equal, the echo return from clouds or precipitation increases with shorter wavelengths. In addition, for the same antenna size, the beam width is narrower at shorter wavelengths, which results in greater resolution. However, attenuation or weakening of the energy in the beam through rain increases at shorter wavelengths. Hence the choice of the operating wavelength of a radar depends on its intended use. For the detection of clouds, short wavelengths near 1 cm are desirable. For the detection of snow or light to moderate rain, the use of 3 cm radar appears optimum. However, 3 cm radiation is attenuated severely in heavy rain, and in regions where large thunderstorms or hurricanes occur frequently the use of 5 cm or even 10 cm radar is desirable. Early in the history of radar, radar frequency bands were designated by code letters for purposes of military security. These designations have been carried over to the present time for convenience, and are regularly employed in referring to weather radars.

Table 1-1 lists five radar bands presently used by precipitation or cloud detection radars, their band designation, wavelength λ, and frequency f. Wavelength is related to the frequency by the formula $f = c/\lambda$ where c is the velocity of light, 3×10^{10} cm/sec.

TABLE 1-1

FREQUENCY BANDS OF WEATHER RADARS

Band Designator	Wavelength (cm)	Frequency f (mc/sec)	Representative Radar Set	Category of Use
L	20	1,500	AN/FPS-7	Surveillance
S	10	3,000	WSR-57	Surveillance
C	5	6,000	AN/FPS-77	Surveillance
X	3	10,000	AN/CPS-9	Surveillance
K_A	0.86	35,000	AN/TPQ-11	Cloud detection

1.6 RADAR BEAM CHARACTERISTICS

1.6.1 Pulse Length

The length of the radar pulse in space is given by the product of the pulse duration and the velocity of light. Thus a one microsecond pulse is 300 meters or about 1,000 feet in length. The length of the pulse limits the observation of detail in range (Fig. 1-4). Two targets on approximately the same azimuth will appear on the radar scope as one whenever the separation between them is equal to or less than one-half the pulse length and as separate targets whenever the distance between them is greater than one-half the pulse length of the set. A finer resolution will be given by a shorter pulse length than a longer one. On the other hand, a longer pulse length, which permits more radiated energy, will enable the radar to detect weaker targets and targets at greater ranges. Use of a relatively long pulse (5 microseconds), which has approximately 5 times as much energy as a 1 microsecond pulse, will permit detection of targets at greater ranges, however, the target resolution will be reduced. For certain purposes, such as cloud detection, a pulse of only 0.5 microseconds has been found to be satisfactory.

1.6.2 Pulse Repetition Frequency (PRF)

The PRF is defined as the number of pulses per unit time. The time interval between pulses is considerably longer than the pulse duration and sets a limit on the maximum range of the radar. The PRF should be high enough so that no target on the horizon will be missed by a revolving radar beam, but low enough to allow sufficient time between pulses to travel to the maximum range and return to the antenna before the start of the next pulse. If the maximum range of the radar is to be r, then the

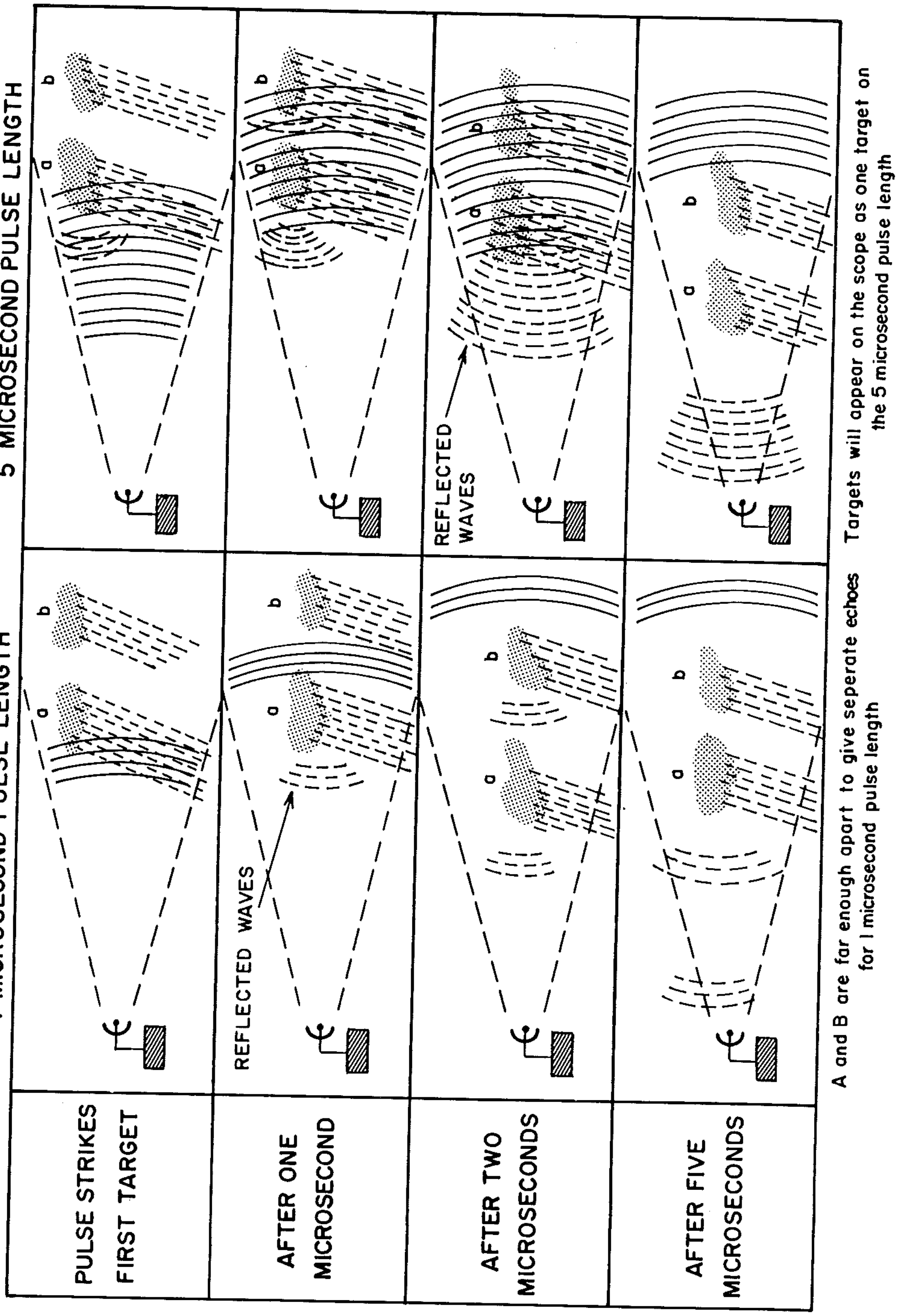

Figure 1-4. Effect of Pulse Length on Radar Resolution [3]

duration between pulses must be at least 2 r/c where c is the velocity of light. Usually a few hundred microseconds more than this limit are added to account for transmission delay in the receiving and display circuits. The PRF is the inverse of this relationship or c/2r. The time duration for a round trip of 1 nautical mile (n. mi.) is 12.36 microseconds, exclusive of time delay in the receiver. This time unit is frequently defined as the "radar mile." The following range-time relationships are frequently useful:

Table 1-1a. Radar Range Time Relationship

Range to Target	Time for Round Trip
1 statute mile	10.74 microseconds
1 nautical mile	12.36 microseconds
1,000 yards	6.1 microseconds
492 feet	1.0 microseconds

Or, in round numbers, it takes one microsecond for a pulse to detect a target at 500 feet. (A microsecond is one-millionth of a second.) The commonly accepted symbol for microsecond is the Greek letter "μ" sec. It may be of interest to note that a pulse travels 984 feet in one microsecond.

In addition, the PRF and the pulse length (τ) are related in the design of the radar transmitter. The average power $P_{(av)}$ provided by a radar is determined by the product of the peak power (P_o) of the radar pulse, the PRF and τ:

$$P_{(av)} = P_o \cdot PRF \cdot \tau .$$

Since the duty cycle of the radar is the product of PRF and τ, the average power is the product of the peak power and the duty cycle.

1.6.3 Beam Width

The pattern of energy emitted by the radar antenna depends on the dimensions of the antenna and the wavelength. For storm detection a typical pattern is symmetrical and conical and consists of a primary lobe (Fig.1-5), which contains most of the energy, and some side lobes in which the energy is reduced by a factor of at least 10^3. The antenna pattern is discussed in more detail in Section 1.3.3.

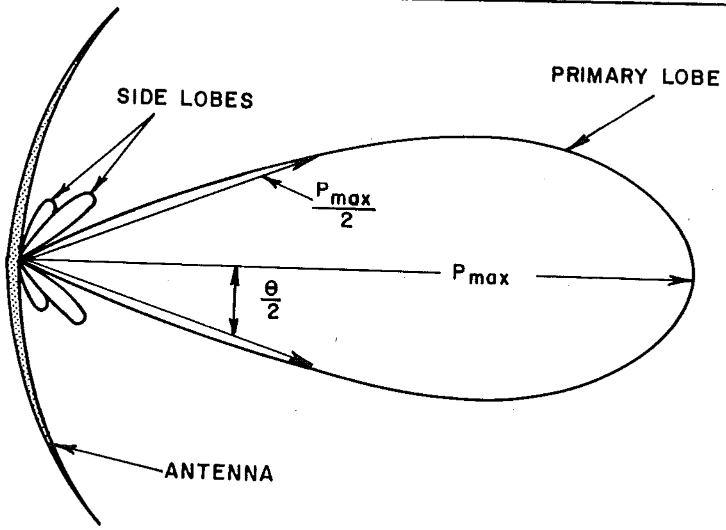

Figure 1-5. Cross Section of a Radar Beam from a Paraboloid Reflector [4]

The maximum power in the beam is in the direction in which the antenna is pointed. It then drops off gradually at first and then sharply. The points in the beam where the power is half the maximum are called the half power points. The beam width is defined as the angular distance between the half power points of the primary lobe. About 75% to 80% of the emitted energy is contained within this volume. An estimate of the beam width (θ) in degrees is given by an empirical expression

$$\theta = 70\,\lambda/d$$

where λ is the wavelength and d is the antenna diameter in the same units. For example, for the AN/FPS-77, λ = 5.5 cm, d = 244 cm (8 ft) and the beam width is 1.6°.

1.6.4 Beam Width Resolution

Two targets approximately the same distance from the radar set will appear on the scope as one, whenever the separation between them is less than the width of the antenna beam; they will appear as separate targets whenever the distance between them exceeds the width of the antenna beam. As a general rule, and for that portion of any target visible on the scope, it can be assumed that the target has been elongated in azimuth by a distance equal to about one beam width at the range involved. Beam width is customarily specified in terms of the angular separation between the half-power points of the main lobe. The actual or effective beam width, however, may vary depending upon target reflectivity, range, and side lobe radiation.

1.7 DATA REMOTING

Since weather radar data are being used more and more for the depiction of significant weather, for pilot briefing and local short range forecasting, additional consumers are demanding weather radar situation displays. Obviously it is uneconomical and in most instances quite redundant to provide an individual radar for each and every requirement or location due to the relatively extensive volume coverage capability of a single radar installation. Consumers within and even beyond radar coverage can have their requirements satisfied through the use of radar data remoting which provides a repeat display of data as gathered at the radar site. Several types of facilities exist and/or can be implemented through appropriate equipment matching to satisfy essentially all requirements which include the remoting of both PPI and RHI data. Most requirements will fall under one of the following categories:

a. Real time raw data - data transmitted immediately as received at the radar site.

b. Delayed time raw data - data temporarily stored for various reasons at the radar site but eventually transmitted as received.

c. Real time synthetic data - data that is semiprocessed but transmitted with essentially no delay.

d. Delayed time synthetic data - data that is semiprocessed and then transmitted at a later time.

Originating and terminal equipment exists in the following forms:

a. Facsimile - where a photograph of the radar site display is transmitted.

b. Television - where either direct camera pickup of the radar display or a photograph of the radar display is transmitted.

c. Digital data link - where processed radar data in digital form is transmitted.

Radar scope information can be remoted from existing radars to nearby (generally less than 50 miles) installations which require these data. This is accomplished by microwave transmission or over high quality coaxial lines. However, considerable cost reduction may be realized by use of a slow scan system which can be transmitted over standard land lines.

Several systems exist which basically perform in a similar manner utilizing slow scan television techniques over a 3 kc telephone line. Figure 1-6 is a generalized block diagram of such a system. The camera, at the originating site, is a typical television unit except for the vidicon tube. In this system the vidicon scans the field of view in a normal raster fashion but stores the information as it scans. Storing the data in the vidicon removes the necessity of a separate storage scan-conversion unit which in turn reduces system cost, complexity, size and power requirements. The camera control provides timing and logic and can be synchronized with radar antenna rotational rate. It also provides for adjustable slow scan raster reading rates and appropriate erasure of the vidicon and timing of the communication control for the transmission of the slow scanned data. The transmission medium can be any narrow band facility, such as land line, multiplexed microwave, multiplexed video or ultra high frequency cabling.

At the terminating site the communication unit demodulates the carrier and recovers the slow scan video data. The display monitor control provides the timing and logic for the reading of the video into the display and erasure cycling of the display tube. The storage display consists of a bright trace storage display cathode ray tube, power supply and appropriate controls for focus, intensity and erasure.

A data remoting system of this type is not limited in application to any one radar or location. Because of optical pickup and the storage capability in the camera, the source data rate is removed providing "free" data for handling in any time scale desired. For example when data are ready for transmission in a system of this type, from 1 to 3 complete pictures can be transmitted in one minute over a 3 kc telephone facility. Any number of terminals with storage displays can be fed from a single originating site. Four grey shades plus white are resolvable in a typical system. A storage display monitor at the originating site provides a check on the picture input to the transmission medium.

A typical application of such a system is the remoting of raw radar data from a Weather Bureau radar site to commercial/military installations lacking radar facilities.

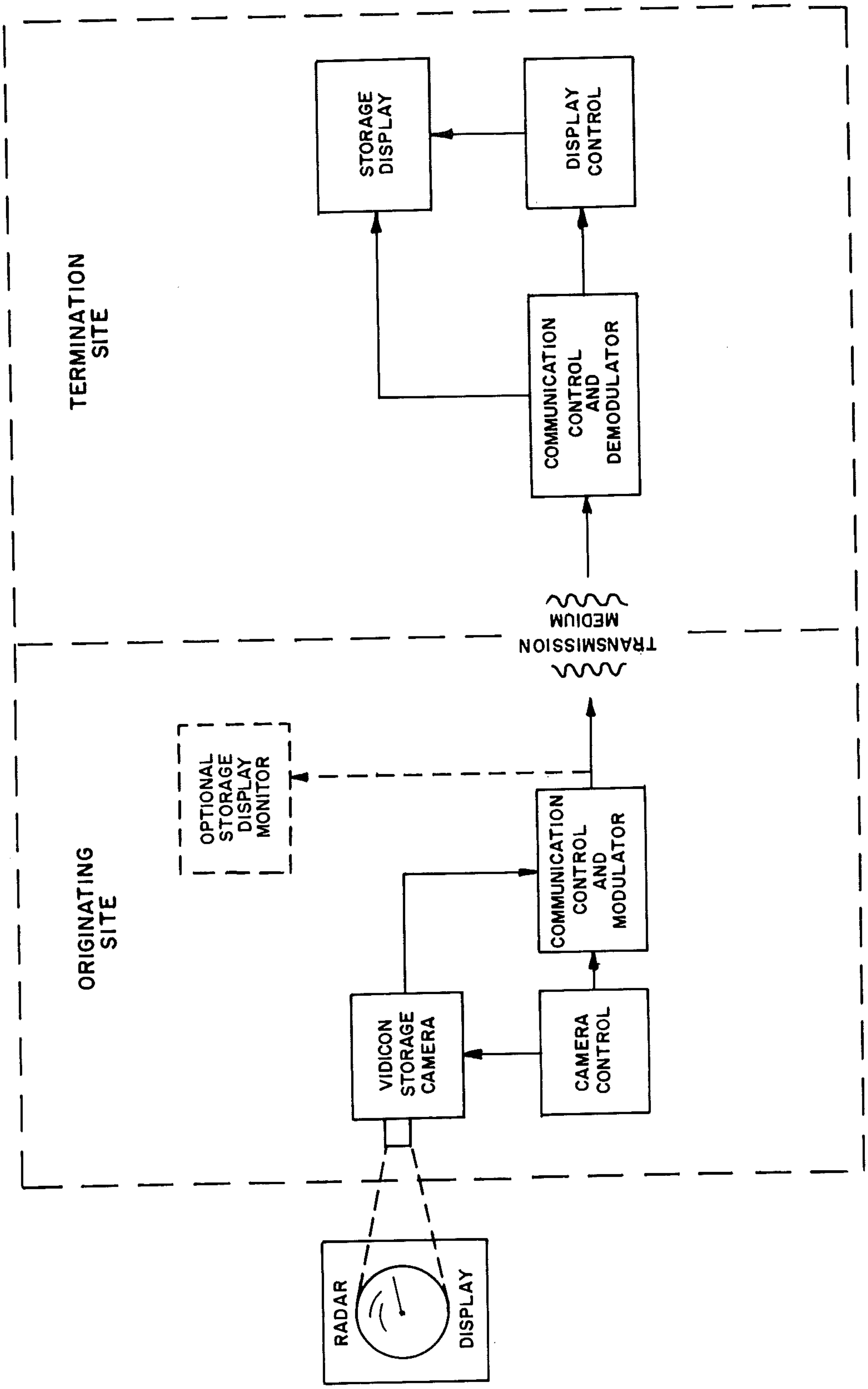

Figure 1-6. Block Diagram of Radar Data Remoting System Employing Slow Scan Television

1.8 REFERENCES

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2. Lhermitte, and D. Atlas: Precipitation Motion by Pulse Doppler Radar. Proc. Ninth Weather Radar Conf. 218-223, 1961

*3. U.S. Weather Bureau: Weather Surveillance Radar Manual. Washington, D. C. 1960

*4. Battan, L.J.:Radar Meteorology. The University of Chicago Press, 1959

5. Skolnik, M. I.: Introduction to Radary Systems. McGraw Hill Book Company, 1962

* References marked with an asterisk (*) are recommended for general reading.

Chapter 2

RADAR PROPAGATION

2.1 REFRACTION

The energy radiated from a radar antenna in a quasi-horizontal direction generally follows a curved path in the atmosphere, due to refraction. This curvature depends on the vertical gradient of the index of refraction. The index of refraction in turn depends primarily on the water vapor content and temperature of the air. Under normal atmospheric conditions, when there is a relatively gradual decrease of temperature and humidity with height, the radius of curvature of the radar beam for nearly horizontal propagation is about four times that of the earth. Thus the distance of the normal radar horizon is about 15% greater than that of the optical horizon (Fig. 2-1). For a more complete discussion of the effects of the atmosphere on radar beam refraction refer to AWS TR 183, "Estimating Meteorological Effects on Radar Propagation."

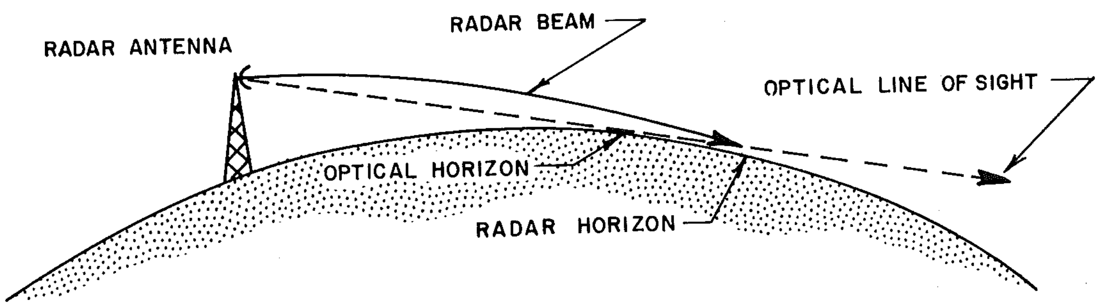

Figure 2-1. Extension of the Radar Horizon Due to Refraction of Radar Waves by the Atmosphere. (The Normal Radar Horizon is about 15% Greater than the Optical Horizon.)

2.2 ANOMALOUS PROPAGATION

2.2.1 Super-Refraction

Under certain atmospheric conditions, the curvature of the radar beam may become greater than normal (Fig. 2-2A); this condition is a type of anomalous propagation and is called super-refraction. Super-refraction occurs when warm dry air overlies relatively cool moist air such as in an inversion. The greater the increase of temperature and/or decrease of moisture with height the greater is the degree of super-refraction. In an extreme case, the radar beam becomes trapped in a "duct" beneath the inversion (Fig. 2-2B), and in this manner it may travel for long distances without appreciable attenuation. Under these conditions targets at low levels, at a few hundred miles distant and not normally detected, may be observed. During precipitation the conditions necessary for super-refraction are normally absent. Several meteorological conditions may lead to super-refraction. Over land, super-refraction is most noticeable at night under conditions favoring strong radiation of heat from the earth. Over the sea it may occur either during the day or at night but is most likely to occur in the late afternoon or evening when warm air drifts over the cool sea. The cool air outflow from a thunderstorm may also produce favorable super-refractive conditions. Ducting occurs relatively frequently in the subtropical high pressure zones. (It would be well for each location to record PPI scope presentations during such abnormal conditions for future reference as an aid in identifying distant targets and distinguishing them from precipitation.)

2.2.2 Subrefraction

Subrefraction, or straightening of the beam upward (Fig. 2-2C) may exist during atmospheric conditions in which the water vapor content increases and the temperature decreases with height. This is the opposite of super-refraction. The maximum range of detection of certain targets may then be reduced. Such a condition may occur in certain types of fog but does not occur in precipitation.

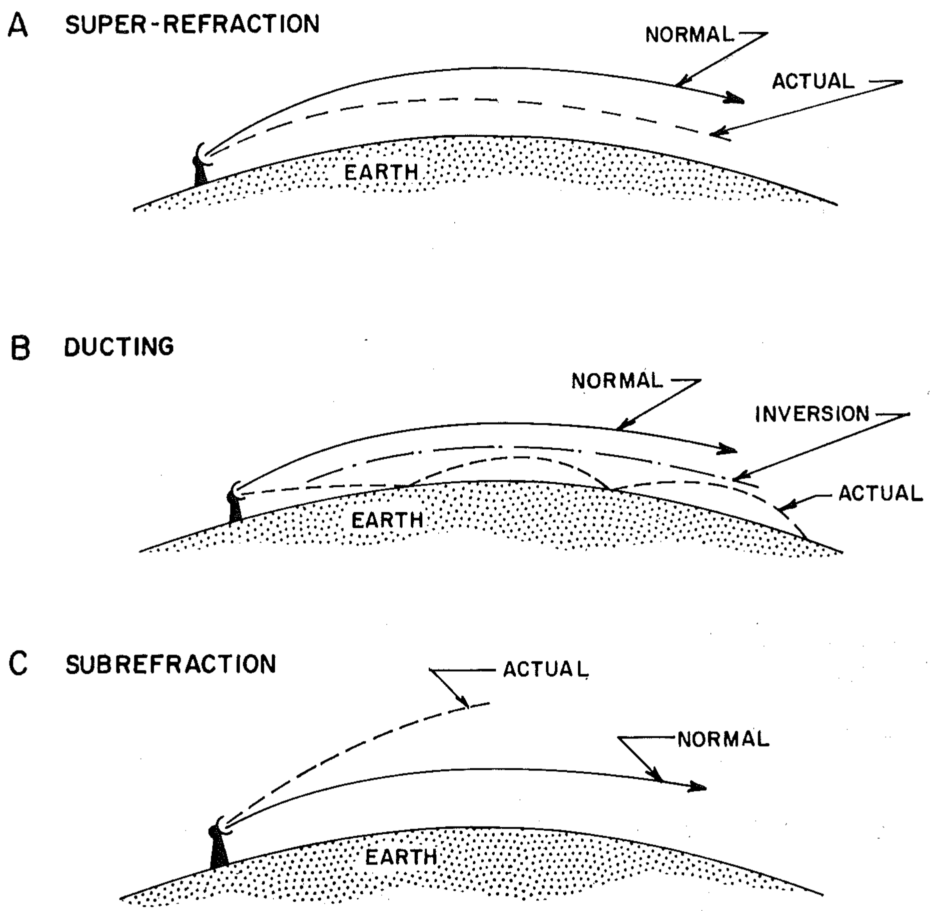

Figure 2-2. Three Types of Anomalous Radar Propagation

2.2.3 Second Trip Echoes

Anomalous propagation may also cause precipitation echoes to be observed on the PPI at locations where no precipitation exists. These are "second trip" echoes, or echoes detected from a previous pulse. It is to be recalled that all echoes are detected by the radar in the interval between pulses. During super-refraction, echoes at long ranges detected by the previous pulse may appear on the indicator. For example, the interval between pulses for the AN/FPS-77 is approximately .00309 seconds. During this period the pulse must travel a distance 2r, where r is the distance between the radar and the target. The maximum range for target detection during that interval is given by

$$r_{max} = \frac{.00309c}{2}$$

where c is the velocity of light or 1.62×10^5 n. mi. / sec. This gives a maximum range of 250 n. mi. Because of processing time in the receiver the actual maximum range is somewhat less. During super-refraction targets at distances greater than 250 n. mi. may appear on the PPI at much closer ranges. Second trip echoes of precipitation have a distorted fuzzy appearance without sharp edges but may be mistaken for actual precipitation echoes at the indicated range (Fig. 2-3). However, they may be verified by tilting the antenna upward slightly (1 to 2 degrees). The second trip echo will disappear almost immediately, whereas the actual precipitation echo will show only a slight decrease in intensity. A change in the PRF, as is possible in the CPS-9, would also cause the second trip echo to disappear at the indicated range.

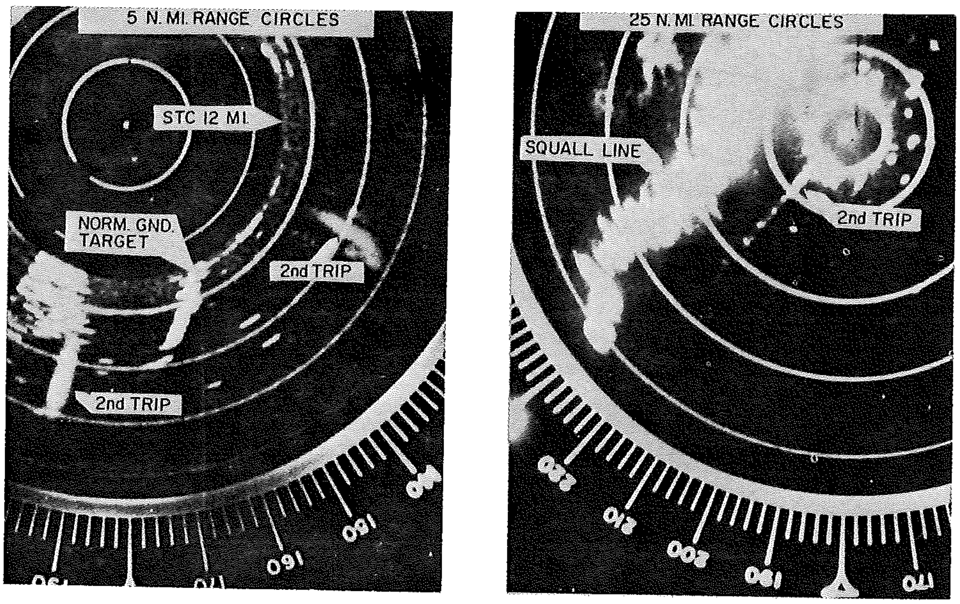

Figure 2-3. 10 cm Radar PPI Photos Showing Examples of Second Trip Echoes. University of Miami Radar. (From Hiser and Freseman "Radar Meteorology")

Chapter 3

RADAR DETECTION AND ATTENUATION

3.1 INTRODUCTION

Radar detection of precipitation depends on the radar characteristics, the distance of the target, its vertical distribution of reflectivity, and on attenuation of atmospheric gases, clouds and precipitation between the radar and the target. Extraneous echoes, such as ground clutter, may sometimes interfere with detection of precipitation.

It is occasionally desirable to measure the power received from precipitation in order to infer its intensity or liquid water content. A radar equation is used for this purpose and each radar may be characterized by a certain radar constant which depends on the wavelength, the antenna gain, peak power, pulse length and beam width.

3.2 UNITS - DB, DBM

The unit of power is usually given in watts. A measure of the relative power gain or loss from a known value is given by the decibel (db). If P_o is the initial value of the power, and P is its value after attenuation due to some process, such as absorption or scattering in the atmosphere, then the relation between the two powers in db is given by

$$db = 10 \log \frac{P_o}{P}$$

Thus if P_o exceeds P by a factor of 2, P is designated as being decreased by 3 db (or 10 log 2). Representative values of db are given in Table 3-1.

TABLE 3-1

REPRESENTATIVE DB VALUES

db	$\frac{P_o}{P}$
1	1.25
3	2
6	4
10	10
13	20
20	100
30	1000

The minimum detectable signal, P_{min}, of a radar is frequently given in units of dbm or decibels with respect to a milliwatt as defined by

$$dbm = 10 \log \frac{P_{min}}{10^{-3}}$$

where P_{min} is expressed in watts. Thus if the minimum detectable signal is 10^{-13} watts, its value is frequently expressed as -100 dbm.

3.3 RADAR EQUATION

If the precipitation particles are small compared to the wavelength, the Rayleigh scattering law is valid and the received power is proportional to Z, or the summation of the sixth power of the particle diameters, and inversely proportional to the fourth power of the wavelength. In storm detection the Rayleigh law is valid for the C and S bands and approximately valid for the X band.

Assuming the Rayleigh law to be valid, the radar equation may be written

$$P_r = \frac{R_c Z \alpha}{r^2} \qquad (1)$$

where P_r is the received power in watts
Z is the reflectivity factor in mm^6/m^3
r is the range in n. mi.

α is an attenuation factor equal to $10^{-0.2\, kr}$ where k is the average attenuation between the radar and the target. Attenuation is discussed in Section 3.6.

R_c is the radar constant

The equation (1) is valid only if the beam is completely filled with precipitation. If it is partially filled, then the right hand side of equation (1) must be multiplied by the fraction of the beam filled with precipitation.

The radar constant depends on the characteristics of the radar. In practical units it is given by

$$R_c = \frac{1.1 \times 10^{-23} P_o \, G^2 \, \theta^2 \, \tau}{\lambda^2} \qquad (2)$$

where P_o is the transmitted peak power in watts
G is the antenna gain
θ is the beam width in degrees assumed symmetric
τ is the pulse duration in microseconds
λ is the wave length in centimeters

The antenna gain is related to the effective area A of the antenna by the formula:

$$G = \frac{4\pi A}{\lambda^2} \tag{3}$$

The effective area is about 65% of the actual area of the antenna.

3.4 BEAM FILLING

As the range increases the volume of air sampled by a radar pulse increases. The beam essentially spreads out both horizontally and vertically extending to greater heights. This is illustrated in Figure 3-1 which shows the 1.6° beam of the AN/FPS-77 at an elevation angle of 1°. At 50 n. mi. the beam diameter is about 8,500 ft. and extends from 2,700 to 11,200 ft. At 100 n. mi. it extends from 8,800 ft. to 25,800 ft.

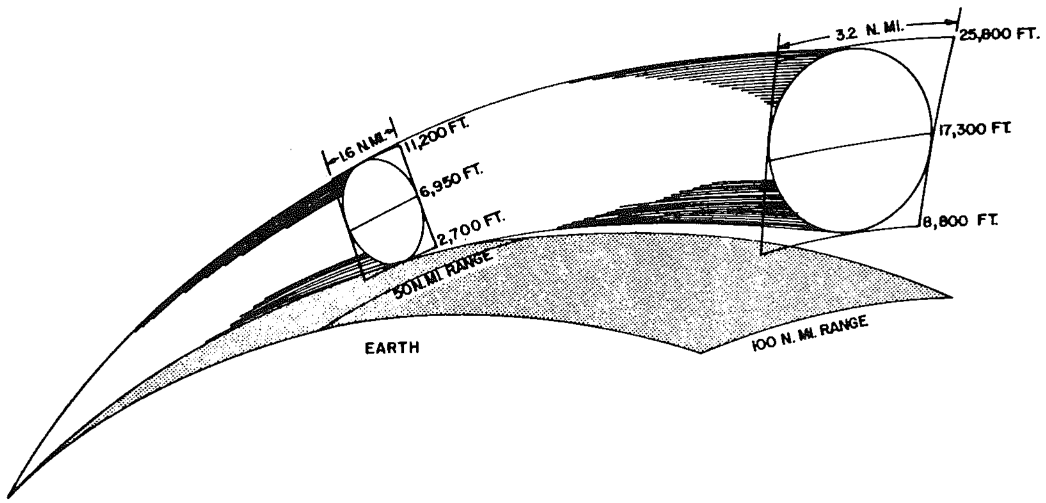

Figure 3-1. Coverage of the 1.6° Beam of the AN/FPS-77 Radar at 1° Elevation

Because many storms have echo tops below 20,000 ft., it is apparent that the beam may not be completely filled with precipitation at greater ranges. In addition, the reflectivity of the precipitation at the upper levels is, generally, considerably smaller than at lower levels.

A consequence of this effect is that beyond a certain range, depending on the beam width and the precipitation structure, the reflectivity of the detected precipitation decreases sharply. In widespread rain, beam filling needs to be considered only along the vertical. For example using the CPS-9 radar in detecting widespread rain with the melting level at 8,000 ft., the reflectivity is fairly constant out to about 45 miles. The reflectivity then rises about 40% at about 60 miles due to the effect of the bright band (see Section 4.4.3) but it drops sharply thereafter until at 110 n. mi. it is only 20% of its original value.

For the detection of showers or thunderstorms beam filling must be considered both horizontally and vertically. Some showers are less than a mile in width and even a 1° beam at 60 miles may not be completely filled. In addition, the most intense portion may cover only a small percentage of the storm area. For thunderstorms the reflectivity for a 1° beam is constant out to about 55 miles, drops by a factor of about 2 at 100 miles, and by a factor of about 20 at 150 miles.

3.5 RANGE EFFECTS

From the radar equation it is apparent that the power received is inversely proportional to the square of the range. Thus, distant echoes of the same intensity should appear considerably weaker than echoes closer to the radar. In addition, distant storms may not fill the beam and only relatively weak echoes may extend about the radar horizon. Thus a line of echoes, such as may occur in a squall line, will appear initially as a few small cells, and then lengthen and increase in intensity as it approaches the radar; the reverse occurs as it recedes from the radar.

In order to compare echoes at different ranges, range normalization is utilized. The purpose of range normalization is to make echoes of equal reflectivity at different ranges appear to have the same echo intensity on the PPI scope and on echo contours. The use of a logarithmic receiver is optimum for range normalization because of its capability of handling a large range of signal intensity without saturation. The AN/FPS-77 and WSR-57 radars are equipped with logarithmic receivers.

In range normalization only the range squared (r^2) correction is generally made while optimum range correction would also consider other factors, such as percentage of beam filling, attenuation, absorption and receiver linearity. Attainment of correction for all of these variable parameters would be an extremely complex function that would have to be capable of being varied with each point target investigated. In situations at appropriate frequencies (e.g., C and S bands) where normal attenuation and absorption have been determined to some degree, a receiver of determined linearity can be readily modified for a good degree of range correction by use of an inverse r^2 gain control voltage. From the point of view of beam filling the r^2 correction is insufficient. As the range increases, the amount of beam filling tends to decrease, and even the echo within the beam may come from the relatively weak precipitation at upper levels or from the sides of convective storms. Although it is possible to to make some empirical correction for the beam filling effect, this is generally not desirable because of the variability of the correction with the intensity of the precipitation and with the height of the melting level. Therefore, the inverse r^2 receiver gain control function, while it is not complete range correction, is a major contribution for range correction. In the AN/FPS-77, with range normalization (STC) applied, the receiver gain is corrected according to a modified inverse r^2 function, seminormalizing the echo to a selectable range of 30, 60 or 120 miles. All echoes within the range selected will then be STC corrected as a function of range. The WSR-57 has an STC effective to 125 miles.

3.6 ATTENUATION

Attenuation is a reduction of the energy in a radar beam due to absorption or scattering in the atmosphere. It may be defined by the equation

$$10 \log \frac{P_r}{P_{r_o}} = -2\int_o^r k\,dr,$$

$$\text{or} \quad P_r = P_{r_o}\, 10^{-0.2\int_o^r k\,dr}$$

where P_r is the received power, and P_{r_o} is the power that would have been received had there been no attenuation over the range o to r. In this form the reduction of power is expressed in db and the attenuation coefficient, k, is expressed in db/n. mi.

3.6.1 Atmospheric and Cloud Attenuation

Absorption by oxygen and water vapor causes attenuation of the radar beam in its propagation through the atmosphere. Oxygen has a strong absorption band near 0.5 cm; water vapor has a weak band near 1.35 cm and stronger bands near 0.2 cm. Absorption also occurs at wave lengths far removed from the band centers. The attenuation depends on the amount of the absorbing gas and on pressure and temperature.

Attenuation due to oxygen is relatively constant at wave lengths above 3 cm. At a range of 100 miles the two-way attenuation is about 2 db.

Attenuation due to water vapor depends on its distribution with height. Because most of the moisture in the atmosphere is concentrated at relatively low levels, most of the attenuation occurs within the first 100 miles of the radar. Over a 100 mile path through a moist atmosphere with a water vapor content of 10g/kg the two-way attenuation is about 3 db for the CPS-9, 1 db for the AN/FPS-77 and 0.3 db for the WSR-57.

Attenuation due to clouds depends on liquid water content. For a cloud having a liquid water content of 1 g/m^3 over a ten-mile path representative of some cumuliform clouds, the two-way attenuation is about 3 db at 3.2 cm, 1 db at 5.5 cm and 0.3 db at 10 cm.

For average conditions, winter and summer, the estimated combined attenuation due to absorption by water vapor and oxygen (no precipitation) is shown in Table 3-2 for 50, 100 and 150 n. mi. paths. Also shown in the table is the estimated attenuation due to clouds over these paths; for these values it was assumed that there were no clouds for the first 25 miles from the radar, because the beam is at low levels, and that the average liquid water content beyond 25 miles was 0.1 g/m^3 for heights up to 15,000 ft.

TABLE 3-2

ESTIMATED TWO-WAY ATMOSPHERIC AND CLOUD ATTENUATION (DB)

	Range N. Mi.	Atmospheric		Cloud
		Winter	Summer	
CPS-9	50	2.2	2.9	0.8
	100	3.5	4.7	2.4
	150	4.2	5.6	3.6
AN/FPS-77	50	1.5	1.8	0.3
	100	2.3	2.6	0.8
	150	2.8	3.3	1.2
WSR-57	50	1.3	1.4	0.1
	100	1.9	2.0	0.2
	150	2.3	2.5	0.4

3.6.2 Precipitation Attenuation

The attenuation due to rain depends on the distribution of drop size and the rain intensity. For a known drop size distribution the attenuation may be calculated from theory.[1]

At 3.2 cm (CPS-9) the two way attenuation as a function of rainfall intensity is shown in Fig. 3-2 for a 10-mile path and a 40-mile path.* For light rain (0.10 in/hr) the attenuation over a 50-mile path is less than 6 db; for moderate rain (0.10 to 0.30 in/hr) it is between 6 and 22 db. Over a 10-mile path of heavy rain (2 in/hr) the attenuation is very serious (amounting to almost 40 db). On the PPI scope, attenuation due to heavy rain can generally be recognized by the typical V-shaped radial notch on the far side of an echo (Fig. 3-3). This has been observed frequently at 3.2 cm but not as yet at 5.5 or 10 cm.

The attenuation at 5.5 cm (AN/FPS-77), shown in Fig. 3-4, is much less serious than that at 3.2 cm. A 2 in/hr rain over a 10-mile path produces less than 8 db; however, the 38 db over a 50-mile path does indicate that attenuation can be serious in cases of detection through widespread heavy rain.

At 10 cm (S-Band) a 2 in/hr rainfall over a 50 n. mi. path produces only about 4 db attenuation. Hence, for all practical purposes attenuation at 10 cm may be neglected. Thus S-band is well suited for detection through heavy rain such as may occur relatively frequently in the tropics or subtropics.

Attenuation due to snow can generally be neglected even at 3.2 cm because maximum snowfall rates are relatively small and because the attenuation due to snow is about a factor of 10 below that of rain of the same intensity.

Although attenuation in the bright band may be somewhat larger than that of the rain, it can generally be neglected because of its relatively small depth and because of the fact that the bright band is generally not present during heavy rain. However, there may be occasions where the bright band is near the ground in moderate or heavy wet snow. In such cases the attenuation at 3.2 cm may be sufficiently enhanced to reduce the range of detection to about 50 n. mi.

3.7 EXTRANEOUS ECHOES

Extraneous echoes may consist of aircraft, clutter, chaff, birds, lightning, or "angels" (interference or any echo not derived from clouds or precipitation).

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* The attenuation is directly proportional to the distance so that the values for 50 miles are 5 times those for 10 miles.

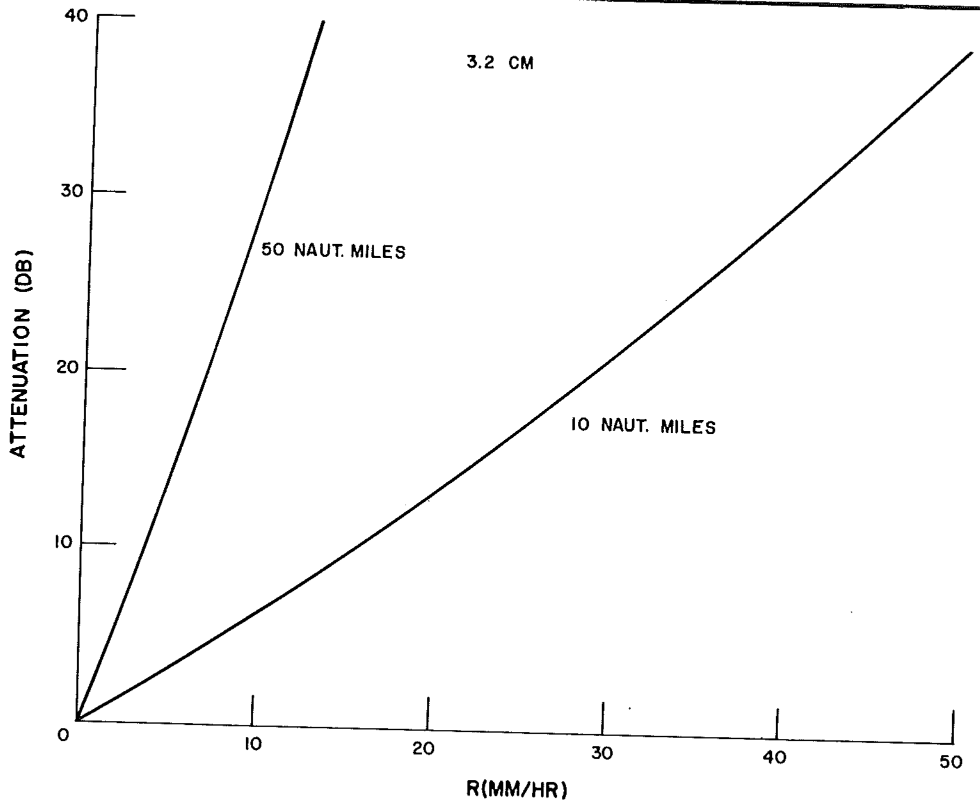

Figure 3-2. Two-Way Attenuation at 3.2 cm as a Function of Rain Intensity, Shown for a 10 and a 50 n. mi. Path

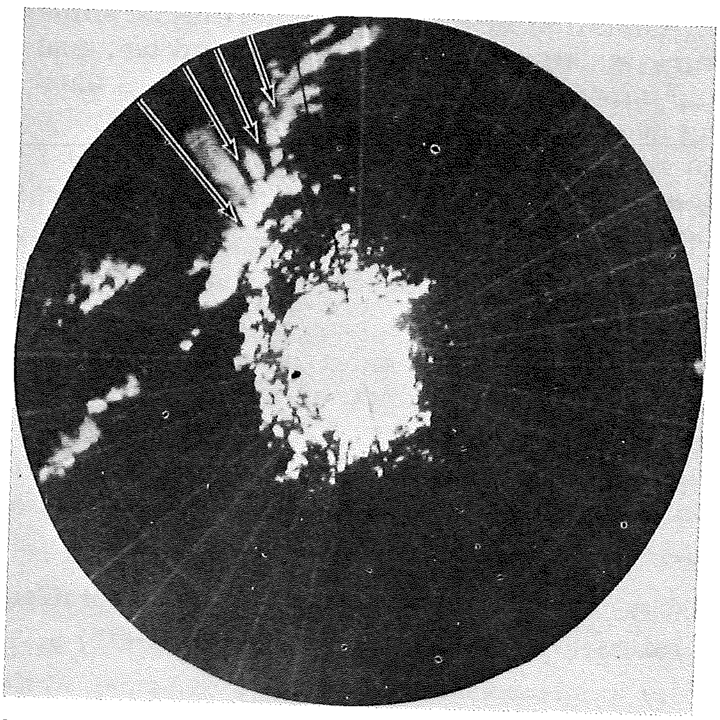

Figure 3-3. CPS-9 PPI of a Squall Line Showing Attenuation Notches (Arrows) at 318°, 326°, 333°, and 340° Caused by Heavy Thunderstorm Rainfall and Hail 19 June 1957. AFCRL Blue Hill Radar 125 sm Range

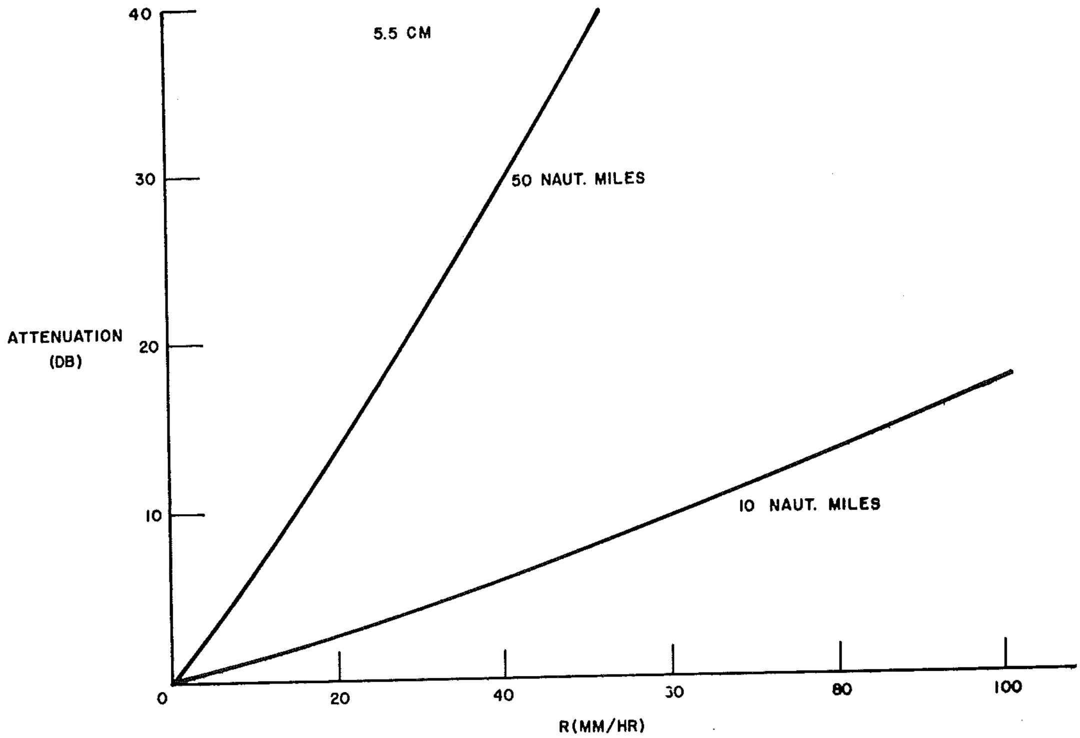

Figure 3-4. Two-Way Attenuation at 5.5 cm as a Function of Rain Intensity Shown for a 10 and a 50 n. mi. Path

Birds, insects or smoke may be responsible for some "angels" (echoes presumed to be from invisible objects). A separate section is devoted to "angels" (see Section 5.1.3). Birds have been observed to form unusual patterns, such as circular rings around dumps.

Clutter is generally defined as a conglomoration of unwanted radar echoes. More specifically it applies to echoes from ground obstructions, such as trees, buildings, hills or sea waves. The higher the radar antenna is above the ground, the more clutter will be detected. Mountains may be detected at ranges beyond 100 miles. Governed by antenna installation criteria, most ground clutter disappears at ranges beyond 40 miles (approximately). Ground clutter interferes with precipitation detection generally at low angles of elevation; much of it disappears when the antenna is raised by 1 or 2 degrees. It may be distinguished from precipitation by examining the echo on an A-scope. Precipitation is characterized by a relatively broad rapidly fluctuating echo caused mostly from Doppler effects, in contrast to the narrow, stable, apparently coherent echo from fixed objects.

Sea return echoes are caused by reflections from the sea surface. The amount of return varies with the roughness of the sea, wavelength of the radar, range, angle of depression of the antenna, and atmospheric conditions. Sea return caused by fluctuating motion of the sea surface may be difficult to recognize. This signal, when observed on an "A" or an "R" scope, has the appearance of a noise signal; and at times will resemble light rain. On the PPI scope, it appears similar to widespread light rain; or may even appear like snow. Sea return signals drop off rapidly with range, and are not as intense as those of heavy rain. When there is steady precipitation at or near the radar it is very difficult to distinguish the precipitation from the sea return signal.

Aircraft are frequently visible on the PPI and appear as point targets with considerable mobility from one sweep to the next.

Interference is caused by extraneous signals radiated by other radar and communications equipment. A moving spiral pattern on the PPI is a common characteristic of interference from another radar. Echoes may usually be seen through the interference.

Chaff consists usually of metallic strips cut to dimensions of half a wave length. They are released in a bundle by aircraft and are scattered by the wind to make highly reflecting targets which may form unusual patterns (Fig. 3-5). If the chaff is designed for the wave length used by the radar, its reflectivity may far exceed that of precipitation; if it is designed for another wave length its reflectivity will generally be much lower.

Lightning creates an ionized column of air which radiates and may form an irregular pattern on the PPI scope. The lightning discharge itself may also appear as a radial spike. Only a small percentage of lightning strokes within range of the radar are observed on the radar display because of unfavorable antenna orientation and obscuration by rain. Nevertheless, paths several tens of miles in length, presumably created by lightning, have been observed which are oriented nearly horizontally along or between clouds at altitudes near 20,000 ft.[2]

3.8 BACK ECHOES (False Azimuth)

Back echoes are caused by back-scattering of radar energy which has been reflected from an obstruction in the vicinity of the radar site.

Because the obstruction must be relatively large (of the order of 1/2 beam width in size) in order to act as a reflector, the obstruction will usually not be located more than several miles from the radar site.

The path of the reflected radar energy depends on the shape and orientation of the obstruction. Generally, the beam will pick up a target behind the antenna, where the energy is scattered back to the obstruction, and then reflected back to the antenna. This produces a target on

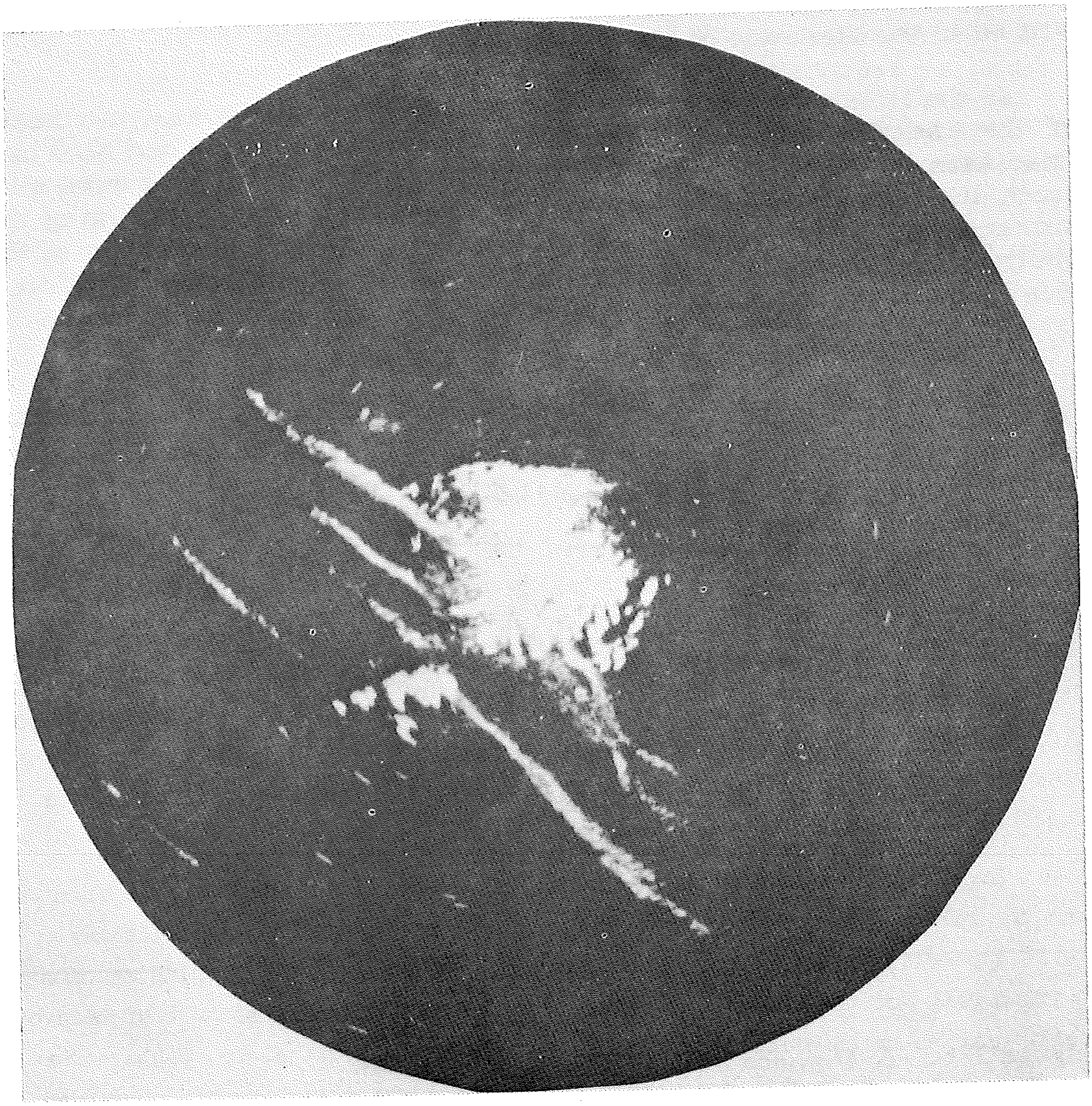

Figure 3-5. WSR-57 (10 cm) PPI Showing Multiple Echo Lines Caused by Chaff. U.S. Weather Bureau Buffalo N.Y. Radar, 100 n. mi. Range.

the scope in the direction of the nearby obstruction, but with a range equal to the distance between the target and the obstruction plus the distance from the antenna to the obstruction. Since the distance from the antenna to the obstruction is small compared to the distance from the antenna to the target, the radar operator should look for back echoes at a range nearly equal to that of the target. The azimuth of the back echo will be in the direction of the obstruction.

In the illustration below the precipitation target to the east-northeast of the radar at range C appears in its correct position and also in a false azimuth position on the PPI scope. The shape of the back echo may show little similarity to the original echo since only a section of the storm may be reflected. The back echo appears in the direction of the obstruction (towards the northwest in this case) with range equal to A plus B, or nearly equal to C.

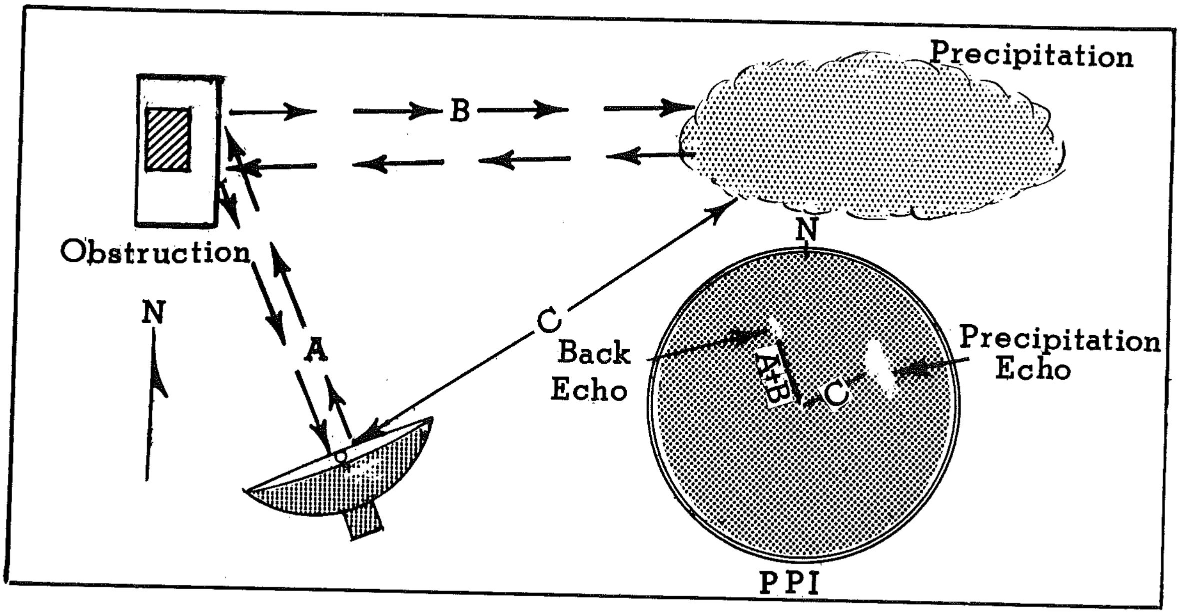

Figure 3-6. A - Distance from Antenna to Obstruction

B - Distance from Obstruction to Precipitation

C - Distance from Antenna to Precipitation

3.9 REFERENCES

*1. Wexler, R., and D. Atlas: Radar Reflectivity and Attenuation of Rain. J. Appl. Met. 2: 276-280, 1963

2. Ligda, M.G.H.: The Uses of Radar for Lightning Observation. Proc. Sixth Weather Radar Conf. 291-296, 1957

* References marked with an asterisk (*) are recommended for general reading.

Chapter 4

PRINCIPAL FUNCTIONS OF THE WEATHER RADAR

4.1 DETECTION OF PRECIPITATION AND MAPPING

The primary functions of a weather radar in either the X, C or S band are to detect and map the precipitation that occurs within the range of detection. These basic functions are accomplished principally on the Plan Position Indicator (PPI), which displays weather target echoes in their proper relative positions as the PPI sweep rotates in synchronization with the antenna. The rotation is usually in a clockwise direction, although some radars, such as the CPS-9 and the WSR-57, may also rotate in a counterclockwise direction. This basic function of the weather radar can be likened to that of an infinite number of observers covering the countryside and instantaneously reporting the occurrence of precipitation to a central collection and display facility.

Before interpreting the echo displayed on the PPI it is very important to be well aware of the fundamental capabilities and limitations of the radar. Of particular significance is the limit of range of detectability of the precipitation under observation. This limit will vary with the type and intensity of precipitation echo as it moves within range. Thus most fields of precipitation which move into range will first appear as very small areas or a few cells even though a very extensive area or line may lie just beyond the range of detection or radar "horizon."

As the precipitation field advances toward the radar, the portion sampled will become larger and more features will become apparent but rarely will a single radar have within its range an entire synoptic scale precipitation field. Therefore, unless there is strong evidence to the contrary, it should be assumed that the precipitation observed on a radar scope represents only a fraction of the existing field, because most precipitation, even in the form of scattered showers, occurs on a scale larger than the observing field of the longest range weather radar.

4.2 CLOUD DETECTION

Weather radars in the C, S and X bands are designed primarily for the detection of precipitation. These radars will generally not detect clouds consisting of water drops with diameters much smaller than 100 microns (μ). Ice clouds in which the particles have an equivalent drop diameter of about 100μ are generally detected by X band sets but less frequently by C and S band sets.

Tests with the WSR-57 radar show that this radar detects up to 25% of cirrostratus clouds visually observed over the radar.[1] A surprisingly large percentage of nonprecipitating middle and low clouds are also observed; up to 50% of the middle category and more than 25% of the low types have been detected by the WSR-57. Many of these, particularly the middle clouds, are supercooled. In such clouds, ice crystals are prone to develop and then quickly grow to detectable sizes. Some low clouds, not supercooled, are also detected, probably by virtue of their large drop size.

Radar detected bases of low and middle clouds are frequently lower than bases measured by ceilometers or visually estimated.[2] Numerous comparisons made between the radar measurements and observer determinations indicate that clouds which have supercooled tops, to -12°C or lower, almost invariably will have lower radar bases. In the case of low clouds, these bases often extend close to the ground. This is the result of the fallout of crystals, which are too sparse to be detected visually or by the ceilometer, but sufficient to be detected by the radar. This effect is less frequently observed below warm clouds.

For reliable cloud detection, it is necessary to use higher frequencies, such as the K_A band (0.86 cm). Based on experience gained with several experimental radars, the AN/TPQ-11 was designed specifically as a cloud detecting radar. This is a fixed beam, vertical-pointing set whose principal display consists of a facsimile time-height record with an A-scope for viewing the instantaneous echoes (Fig. 4-1). This set detects all clouds composed in whole or in part of ice particles and all water clouds which are sufficiently extensive or dense so as to become significant in the operation of aircraft. Fair-weather cumulus and thin scattered patches of stratocumulus usually will not be detected because of the lack of large droplets; while stratus, even a relatively thin layer, dense strato-cumulus and cumulus congestus will be indicated. If the clouds are nonprecipitating, several layers may be identified; as many as six have been observed simultaneously. When precipitation is reaching the ground, usually only the top of the deck from which the precipitation originates can be distinguished -- all lower layers are obliterated by the much stronger echo of the precipitation itself.

The cloud detector radar gives the forecaster an accurate observation of the present cloud structure overhead and its trend in the past. It is most valuable during low overcast conditions when the cloud cover directly overhead is representative of a reasonably large area.

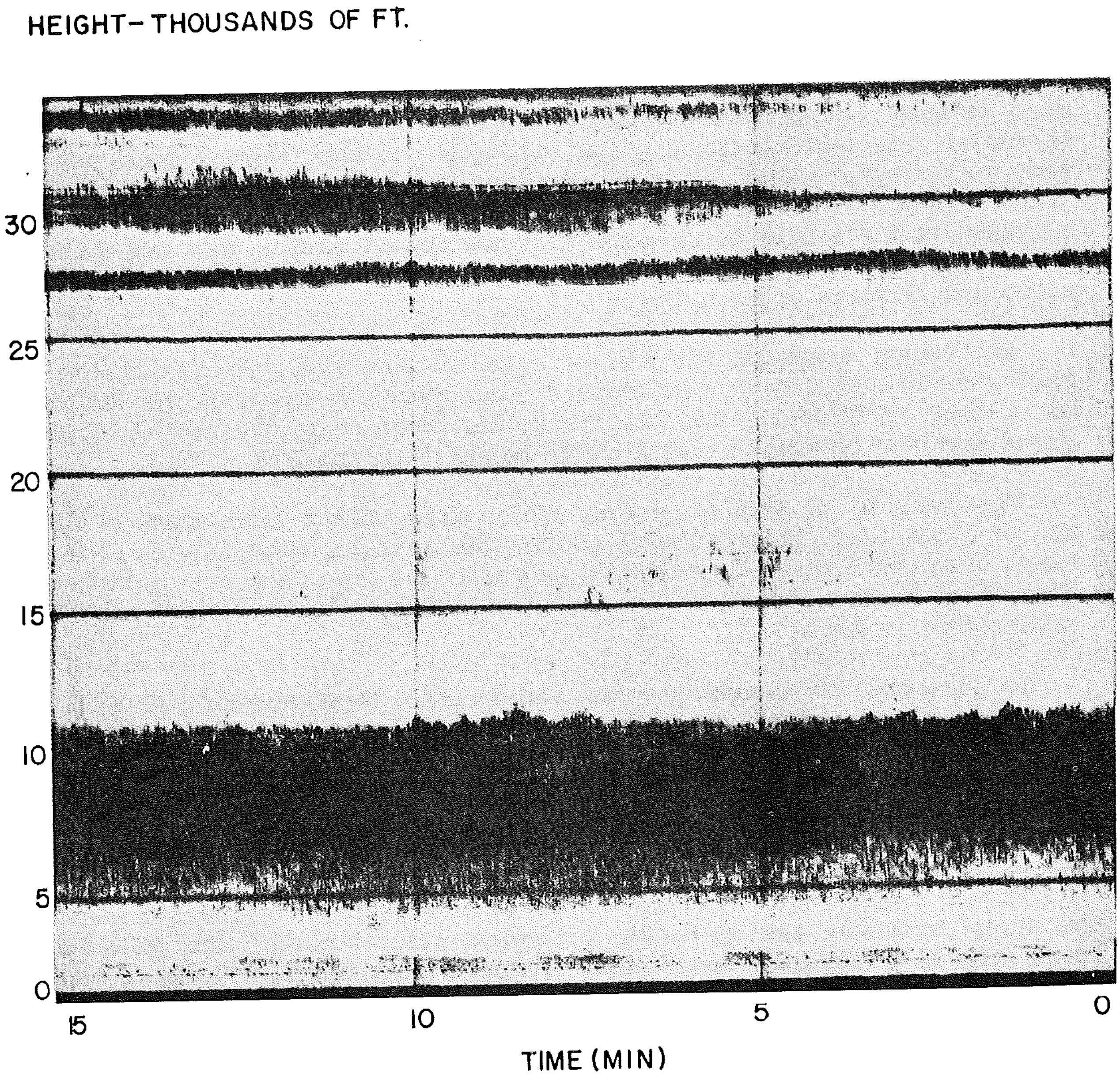

Figure 4-1. Sample AN/TPQ-11 Facsimile Time-Height Record of Five Cloud Layers

4.3 HEIGHT MEASUREMENT

On a conventional weather radar in either the X, C or S band, determination of echo height is most readily made by use of the RHI (Range Height Indicator). Use of this feature is limited to within 100 or 125 miles of the radar, which is about the limit of useful accuracy in measuring echo heights. Height measurements should be a routine part of the observation schedule regardless of the type of echo. During continuous widespread echoes, the height measurement provides the forecaster with much valuable information regarding the origin of the precipitation. Changes in the height of the echo tops have considerable significance in estimating the duration of the precipitation at the ground and are also related to changes in intensity.

The height scale on the RHI of some radars (e.g., AN/FPS-77) includes the effect of earth curvature. No correction is made on the RHI of the CPS-9 or WSR-57, and heights of the beam center beyond about 35 miles are best obtained using a range height diagram (Fig. 4-2).

The heights of echo tops may differ appreciably from those of the actual cloud tops. In stratiform clouds the echo top is a function of the range because of the weak reflectivities near the top of the precipitation. Echo tops in such precipitation are best obtained by the RHI at ranges of 20 miles or less.

In showers or thunderstorms radar echo tops determined by the elevation of the radar antenna are generally higher than the actual cloud tops. On the average, the radar echo tops exceed the actual cloud tops by an amount up to one half the beam width.[3] However, subtraction of half a beam width gives no assurance of accuracy since the apparent height of the echo tops depends on the distribution of reflectivity within the storm. In the case of intense echoes with Z exceeding 10^5 mm^6/m^3, it has been suggested[4] that for better accuracy, echo top measurement be made at lower gain settings. On some radars, notably the WSR-57, high intensity echoes, presumably from a hail shaft in the core of a thunderstorm, may produce a false top on the RHI due to an echo from a side lobe of the antenna. Under careful observation, this is recognizable and may even be used operationally as a means of detecting the presence of hail shafts. This spurious effect is discussed again in Section 5.1.2.3.4.

Measurements made beyond 100 miles are subject to increasing errors due to beam width effects and errors in the elevation angle which can be read only to an accuracy of about 0.5°. An additional source of error is the variation in the curvature of the beam, such as in anomalous

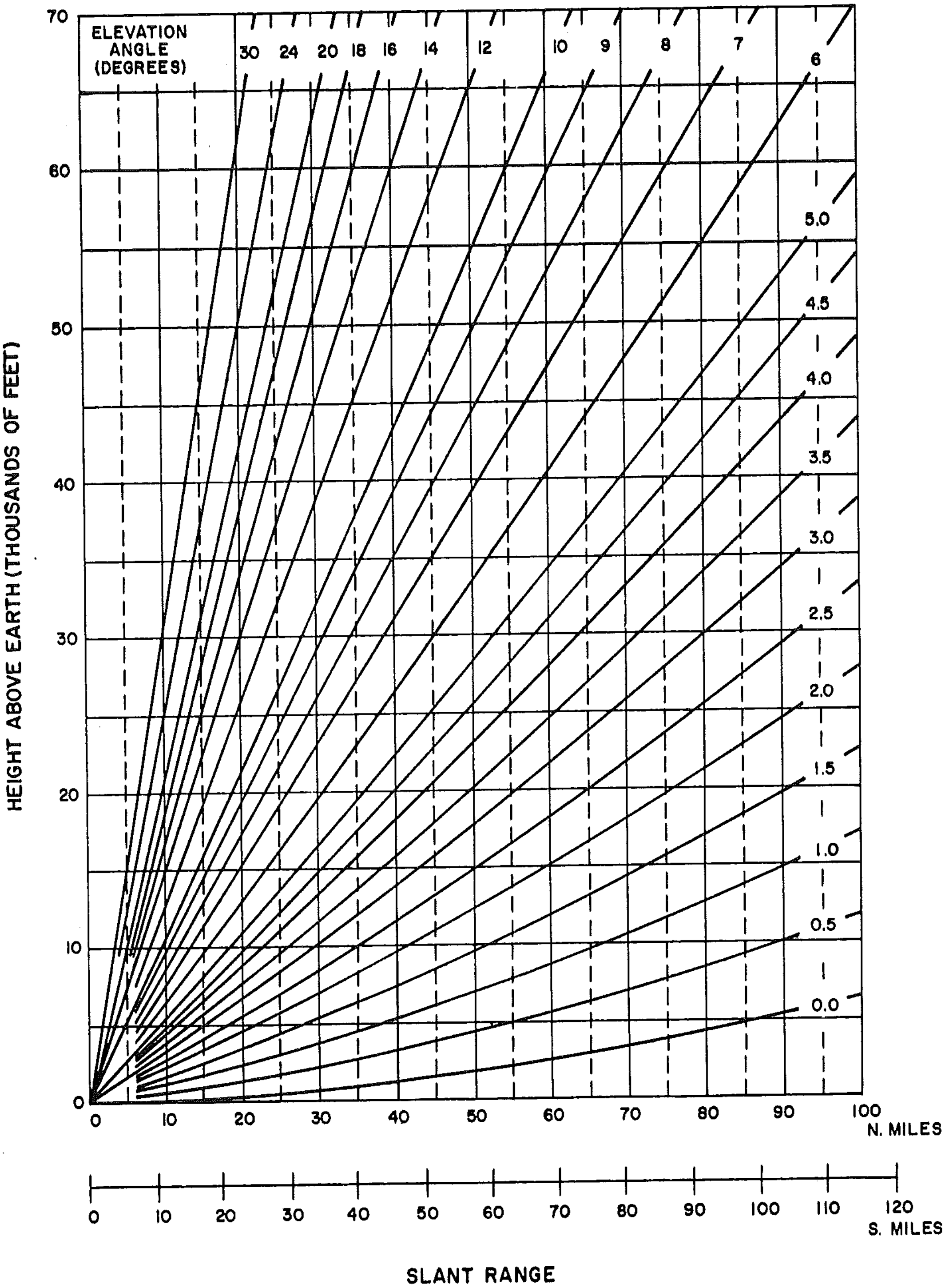

Figure 4-2. Range Height Diagram Giving Apparent Height of Radar Echo as a Function of Slant Range and Elevation Angle

propagation. Effects such as these may account for discrepancies of 30,000 feet in echo tops as measured by two radars, one close to the storm, the other more than 100 miles away. Invariably the distant radar over estimates the echo top. The effect of distance on height measurements is also illustrated in Figure 4-3 which shows the distribution of echo tops with distance as measured with the AN/FPS-77. A rise in the average echo top with distance is evident. Part of this rise may be real because at longer ranges only the more intense and taller echoes would be detected, but there is no valid reason why the maximum echo top should increase with range.

On a K_A band cloud detector radar such as the AN/TPQ-11, tops and bases of clouds, in the absence of precipitation, can be measured very readily on the A-scope and from the facsimile THI (Time Height Indicator) record. In case of precipitation, usually only the height of the uppermost layer can be determined, but this is valuable information.

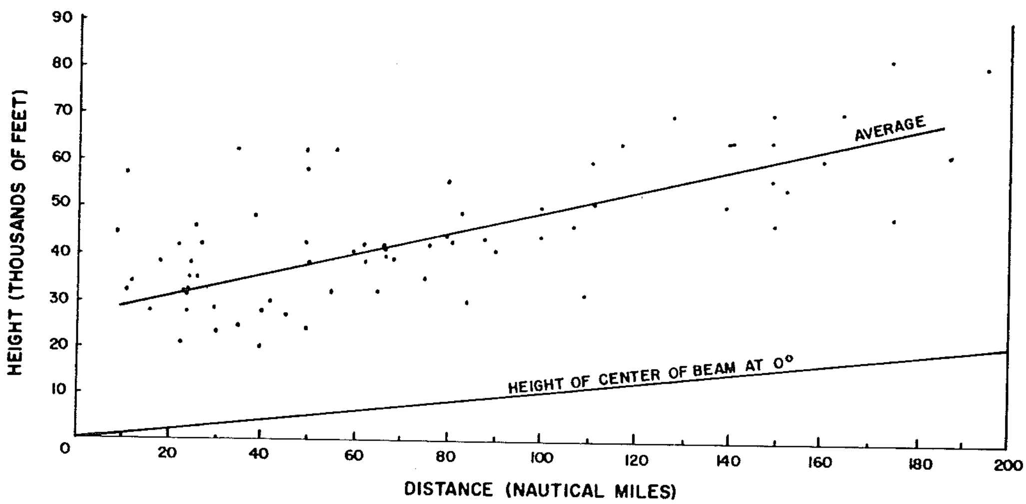

Figure 4-3. Distribution of Echo Tops with Distance as Measured by AN/FPS-77 Radar

4.4 CHARACTER OF CLOUDS AND PRECIPITATION

4.4.1 PPI Observations

The texture and pattern of the echo as it is displayed on the PPI scope varies over a wide range from a uniform, very nearly smooth echo to isolated cells of high intensity echo. The greatest variation shows in middle intensity echoes and occurs in middle latitudes where the seasonal effect is the greatest In these regions, the smoother echo, also called stratiform, predominates in the winter season while cellular or convective echoes characterize the warmer part of the year. In addition to the seasonal effect, echo types are related to the types of weather system producing them. Thus, cyclonic precipitatpon has predominantly stratiform echo in the continuous precipitation area, while precipitation associated with cold fronts, troughs and squall lines has predominantly convective echoes. There are many combinations of types. Even in winter storms in higher latitudes, the initial smooth echo often gives way to a combination of cells imbedded in the stratiform echo. Again predominantly cellular echo fields may also have stratiform regions. In lower latitudes, a much larger proportion of echo fields are convective, but even here stratiform echoes are encountered.

The largest percentage of echo fields consist of more or less random echoes having very little systematic arragnement or sequence. However, there are a number of weather systems which display a recognizable sequence of echo types. The most notable example occurs with higher and middle latitude cyclones during the colder part of the year.

4.4.2 RHI Observations

The character of echoes as displayed on the RHI is largely determined by the pattern, with very little being recognizable in the way of texture. Because of the greatly exaggerated vertical scale, much of the pattern information is lost unless a small range, not over 25 miles, is used in scanning the vertical. The 100 mile range should generally be utilized for observing convective storms. In the vertical, even the echo which appears smooth on the PPI usually has a recognizable pattern. The tops will show some characteristic form or slanting streamers will be visible. The greatest variety is in the echo tops which can range from relatively smooth to extremely accentuated or ragged even for cases of widespread echo. The echo may be relatively uniform in intensity, as in the early stages of cold-season cyclonic precipitation or it may have high intensity cells or cores imbedded within the uniform low intensity echo. Patterned echoes on the PPI will result in greater variability on the RHI. The RHI patterns contain much information of value in estimating turbulence, icing and precipitation growth.

A striking feature observable in stratiform rain on the RHI is the bright band (Fig. 4-4), a horizontal layer of enhanced reflectivity about 1,000 feet in depth. The bright band occurs in the region of melting snow about 1,000 feet below the melting level (0°C), and is always present in widespread rain with its altitude ranging from 5,000 to 8,000 feet in winter and from 12,000 to 15,000 feet in summer or in lower latitudes. The bright band is not present in the active parts of thunderstorms because in the strong updrafts there is no clear-cut altitude above which the

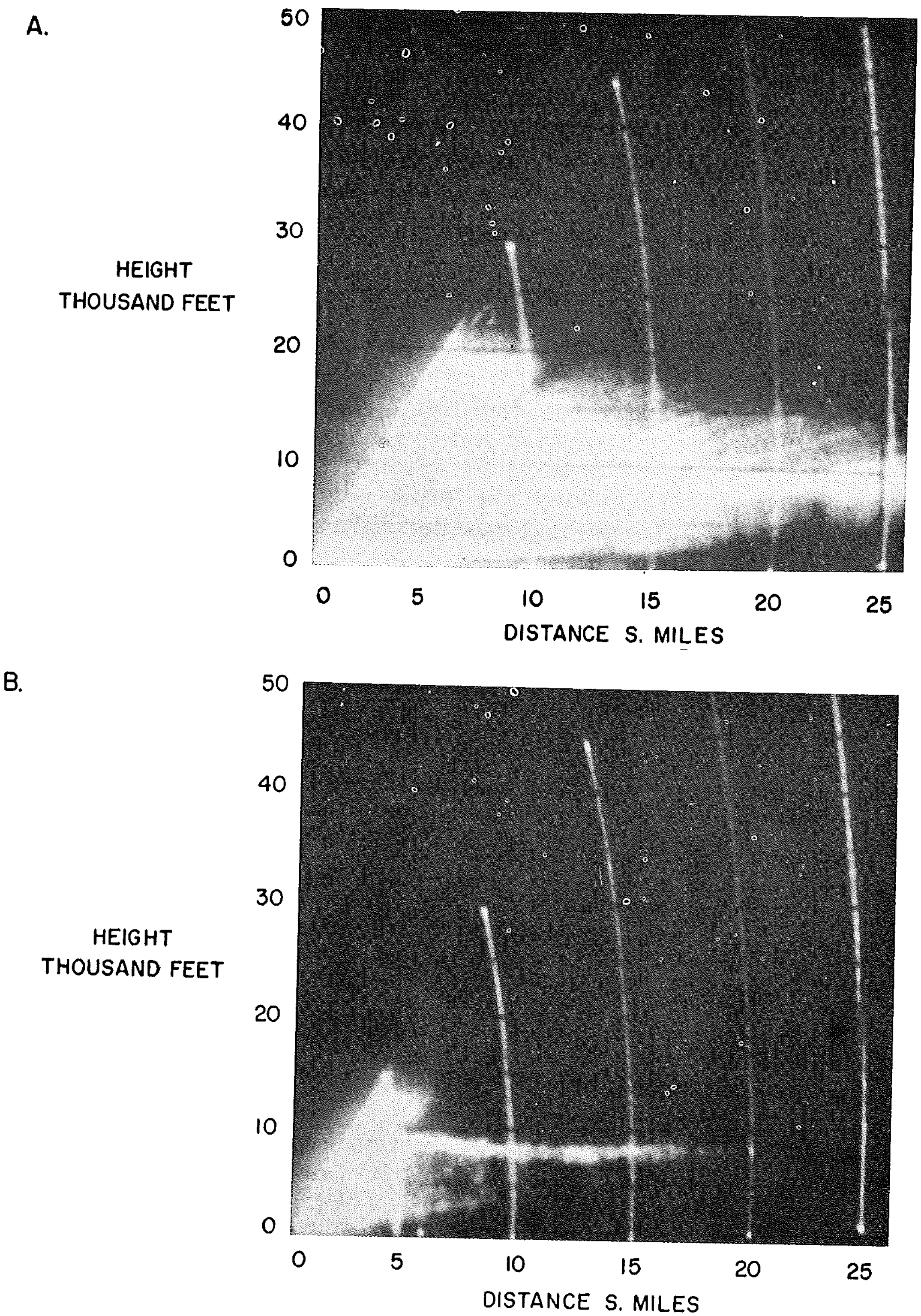

Figure 4-4. CPS-9 RHI in Uniform Rain, A. at Full Gain, B. at Gain Reduction of about 20 db Showing Bright Band at 8,000 ft M.I.T. Radar 25 sm Range

precipitation is predominantly ice and below which it is water. However, the bright band is present in mature or decadent thunderstorms in areas of relatively gentle precipitation where strong updrafts no longer occur.

In order to more clearly identify the bright band and its characteristics, RHI scans at short range and at reduced gain, about 30 db, should be made occasionally during observations in rain. Observations of the characteristics of the bright band, such as its height, depth and changes with time, are among the more useful functions of the RHI.

4.4.3 Physical Explanation of the Bright Band

The various physical factors that influence reflectivity changes in the bright band are (1) the change in the dielectric constant from that of ice to that of water (2) the change in the fall velocity of precipitation particles through the melting layer (3) coalescence or the combining of individual snow crystals into snowflakes or clusters of crystal (4) shape effects, or deviations from the spherical shape in melting snow and (5) growth of precipitation particles.[5]

The first two physical factors are the basic cause of the bright band. After the snow falls below the melting level it acquires a coating of water which effectively changes its dielectric constant and causes an increase in reflectivity by a factor of about five. This makes a peak of reflectivity at the bright band. By the time melting is completed, the fall velocity of the raindrops has increased to about five times that of the snowflakes. Due to the increased velocity the vertical spacing of the raindrops is five times as great as that of the snowflakes and hence the concentration of the number of raindrops becomes one fifth that of the snow, thus tending to decrease the reflectivity. In the upper portion of the bright band the increase in dielectric constant occurs without appreciable change in the fall velocity while in the lower portion an increase in fall velocity occurs with little or no change in dielectric constant.

Coalescence is a more gradual process occuring both in the snow above the melting level and in the bright band. For every two snow crystals of the same water content that coalesce, the reflectivity increases by a factor of two. At low temperatures, below about -5°C, there is little tendency for coalescence to occur and snow mostly consists of single crystals. With increasing temperature, coalescence increases, possibly due to a greater cohesive property of the crystals. In the melting layer itself the snowflakes are frequently observed to a very large, sometimes as much as three to four inches in diameter. Breakup of the large snowflakes into smaller raindrops may occur when melting is completed. Coalescence and breakup may be a highly variable factor.

Both the shape and the orientation of melting snow has an effect on the reflectivity. Disc-shaped objects, such as snowflakes, have a tendency to fall with their maximum areas horizontal, although the zig-zag motion of falling snowflakes diminishes the orientation effect. According to observation the shape effects amount to about 1.5 db between the bright band and the snow or rain.

Growth of snow crystals may occur by sublimation deposit on the crystals from the vapor state, or it may occur by accretion (the capture of small cloud drops in their path). In widespread precipitation, clouds are stratiform and updrafts are relatively small, so that only growth by sublimation is important. In shower clouds with stronger updrafts, growth by accretion is favored. Sublimation is maximum at temperatures between -10°C and -20°C and does not occur at 0°C. In the melting layer, growth by condensation occurs due to the cooling effect of melting snow but in the absence of updrafts this effect is small and increases the reflectivity by about 12%. Table 4-1 shows estimated typical magnitudes of the various effects in the 2,000 ft. layers above and below the middle of the bright band.

TABLE 4-1

AVERAGE ECHO INTENSITY CHANGES DUE TO

PHYSICAL FACTORS ABOVE AND BELOW THE BRIGHT BAND (BB)

Factor	Snow down to BB (db)	BB to rain below (db)
Dielectric	+4	+1
Fall velocity	-1.5	-5.5
Coalescence or breakup	+3	-1
Shape	+1.5	-1.5
Growth	0	+0.5
TOTAL	+7	-6.5

The change in reflectivity from the snow to the middle of the bright band is very sensitive to the depth of the layer chosen because the reflectivity generally decreases fairly rapidly above the 0°C level amounting to about 3 db in the first 600 feet. Above that level the decrease is more gradual.

4.5 MEASUREMENT OF ECHO INTENSITY

Precipitation echoes observed by radar, besides having recognizable and characteristic patterns, also contain useful information concerning the intensity and distribution of intensity of the echo itself. An experienced operator is able to distinguish in a qualitative manner between relatively weak, moderate or strong echoes by examining the scopes at maximum operating gain settings. This information, however, is of very limited value and does not make efficient use of the capabilities of modern weather radar equipment. Present day weather radars incorporate a means of systematically decreasing the receiver gain by inserting a measured degree of attenuation into the receiver input. This permits a contouring of the echoes and the determination of intensity gradients and maximum intensities. This quantitative information can then be translated in terms of estimated precipitation rate and probable degree of storm severity in the case of thunderstorms. Because of the radar bias toward the larger particle size (Section 1.4) there can be no unique relationship between radar echo intensity, regardless of how accurately it is measured, and the precise rate of precipitation. The increased reflectivity in the bright band (Section 4.4.3) must also be considered in determining precipitation intensity in widespread rain. Various models of precipitation based on empirical and theoretical considerations will be used in deriving quantitative techniques of precipitation estimation by radar in Chapter 7.

4.5.1 PPI AND A-SCOPE

The PPI is the indicator most commonly used for weather surveillance by radar. Therefore, much of the echo intensity determination will be performed on this scope. For many purposes, gain reduction in steps is accomplished by using the stepped attenuator. On some radars this consists of a coarse attenuator which lowers the gain by large steps and a fine attenuator which lowers the gain by smaller steps. The coarse attenuator will give a first estimate of the attenuation needed to blank out the echo, or it may be used to survey the entire scope to determine quickly the region where the most intense echoes are located. For determining the actual echo intensity, the fine attenuator is used in conjunction with the A-scope to determine the attenuator setting that will reduce the echo to a reference line or base line. This technique may be used for both widespread snow and rain and thunderstorm echoes. If comparisons are to be made between echoes at different ranges, range normalization, if available should be employed. In estimating the severity of thunderstorms, an iso-echo contouring device may be employed. This device inverts the signal beyond a preselected level and produces a "hole" in the echo displayed on the PPI when the echo intensity exceeds this level.

The iso-echo device provides a rapid means of locating the highest intensity echoes out of an echo field and approximating the strength of the echoes; however, the gain reduction technique is still recommended to arrive at a close estimation of the intensity.

4.5.2 RHI

Observations at reduced gain on the RHI may be made in showers or thunderstorms to detect and locate the high intensity cores and to determine the presence of a severe or potentially severe thunderstorm. When observing widespread rain, a reduced gain RHI will quickly detect the presence of the bright band and its altitude (Figure 4-4).

4.6 ECHO MOTION

In discussing the motion of radar echoes, it is useful to consider briefly the synoptic scale patterns or systems which favor the development of precipitation fields. These fields may appear on the PPI as areas of relatively uniform echo or many small echo areas or even cells. The actual configuration within the precipitation field will depend on the type of synoptic system, the season, the time of day and the geographical location. The field of precipitation associated with a synoptic system encompasses an area generally considerably larger than the range of a single radar. The field itself has a motion which may be related to, but is not necessarily the same as that of low pressure systems or troughs at any level in the atmosphere. For forecasting purposes it is quite important to determine the field motion because this largely determines the motion of the precipitation.

4.6.1 Motion of Echo Fields

Motion of echo field is most difficult to determine because the radar sees only a portion of the field. As the field enters the range of the radar, the forward edge of the field may be observed and its motion will give some indication of the motion of the field. The important feature as far as the radar site or other terminal is concerned is the component of the field motion in the direction of the radar or terminal. This may be readily determined from lines or other fields having relatively sharp edges but is difficult when the field is made up of irregularly spaced elements.

4.6.2 Motion of Cells and Elements

The easiest and most useful motion to determine, is that of a small cell. Although this is of limited value in forecasting the future behavior of a cell because its lifetime is quite short, of the order of less than one hour, it provides information on the winds aloft. It has been found that the motion of cells (single cells or small clusters which may appear as one cell on the radar) is closely related to the wind velocity at the 700 mb level and to the mean wind between 5,000 and 20,000 feet (or between the 850 mb and 500 mb levels). When the cells are arranged in a line, the line motion is found to be very nearly equal to the component of the cell motion perpendicular to the line. In this case the cell motion is useful in estimating line motion. Cell motion may be determined by tracing successive positions of several small cells on the PPI at 15 or 20 minute intervals. Using the average speed and direction of several cells will yield a representative value. Widespread precipitation echoes, even those giving a rather smooth appearance on the PPI, are composed of elements which have been found also to move with the direction of the 700 mb wind. The motion of these elements is not usually detectable except by time-lapse photography, hence this information is of little practical usefulness.

4.6.3 Motion of Large Convective Echoes

Large convective echoes 15 n. mi. or more in diameter are associated with thunderstorm complexes composed of many individual thunderstorms. Unlike the smaller cell, the large echo masses do not move with the wind at any level nor with the 850-300 mb layer mean wind. The echo speed is generally less than the wind speed and the direction of echo advance is nearly always to the right of the upper winds by an average of about 15° but varying between 0° and 40°.[6] The interpretation for this behavior is the formation of new convective cells, predominantly on the right flank, which cause the echo mass to "grow" or propagate in that direction at the same time as the old cells advance through the thunderstorm complex with the upper wind flow. This process is frequently accompanied by dissipation on the left flank. Once the echo attains the stage of a thunderstorm complex, its motion becomes relatively conservative and the rate of propagation and translation approaches a steady state. Hence, the speed and direction of such an echo as determined by radar from successive observations made at 15 or 20 minute intervals will be useful in extrapolating future motion for a period of up to three hours, in the absence of a sudden change in the size of the echo cluster.

4.6.4 Motion of Echo Lines

Echo lines are a special case of an echo field where the cells or cell clusters are located predominantly along a straight or slightly curved line. The most common line is one made up of thunderstorms and convective showers but lines may range from an assemblage of weak cells accompanying a winter-time cold front to a chain of violent thunderstorms in a summer squall line. Studies of lines which persist for a few hours, indicate a conservative speed and direction of travel through their lifetimes. The direction of line motion, defined as perpendicular or normal to the orientation, lies to the right of the direction of the individual cells and of the 700 mb wind or the 850 to 500 mb layer mean wind, [7, 8] at an angle which remains nearly constant for a particular line, but which may vary from 0° to 90°. The speed of the line has been found to approximate closely the component of the cell motion or of the 700 mb wind normal to it or the component of the layer mean wind, 850 mb to 500 mb. At low line speeds, below about 20 knots, the convective line speed is somewhat greater than the wind component, apparently due to new cell growth in advance of the existing line. In an extreme case, a line with the wind parallel to it advanced at a speed of 10 knots.

4.7 REFERENCES

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* References marked with an asterisk (*) are recommended for general reading.

Chapter 5

USES OF RADAR IN SYNOPTIC METEOROLOGY

5.1 FUNCTION IN WEATHER ANALYSIS AND DEPICTION

5.1.1 Synoptic Scale Systems

Under this category are found cyclones of the temperate latitudes, fronts and tropical storms including hurricanes as well as lesser precipitation systems which are not related to frontal configurations but associated with centers of these systems. A single radar will indicate only a portion of the existing field of precipitation echo. This portion, however, contains essential information useful to the forecaster. This information consists of pattern, echo character, coverage, intensity and motion, all of which are necessary in forecasting. In general, developing cyclones, both tropical and extra-tropical, exhibit characteristic sequences of precipitation echo patterns. On the other hand the precipitation patterns accompanying fronts and non-frontal vertical motion fields show great variability and a lack of interdependence between precipitation and the front.

5.1.1.1 Winter Cyclones

Cold season cyclonic storms, especially those of higher latitudes exhibit characteristic patterns of precipitation echo with only relatively minor departures from storm to storm. A typical sequence for a snowstorm, has the first echo on the PPI appearing at a range of about 100 $\pm$ 20 n. mi. and often characterized by a fairly sharp leading edge. The echo is usually quite featureless in the beginning except for some minor banding (Fig. 5-1). On the RHI the echo will appear overhead several hours before the snow reaches the radar. Initial appearance is at the cirrus level, above 20,000 feet, and the echo intensity gradually increases as the base lowers rather steadily. At this stage the RHI may display characteristic downward protrusions of echoes, termed "stalactites". These are ascribed to the destabilizing effect of evaporative cooling of snow falling into dry, initially stable air (Fig. 5-2). The overhead rate of descent of the echo has forecast implications, which will be discussed in a later section, and is, therefore, a feature which should be carefully observed.

As the center of the cyclone comes closer to the radar (within 200 miles) a change in the echo character becomes apparent in the direction of the approaching cyclone center. A transition occurs from smooth, slightly banded echo, to a more patterned or structured echo consisting

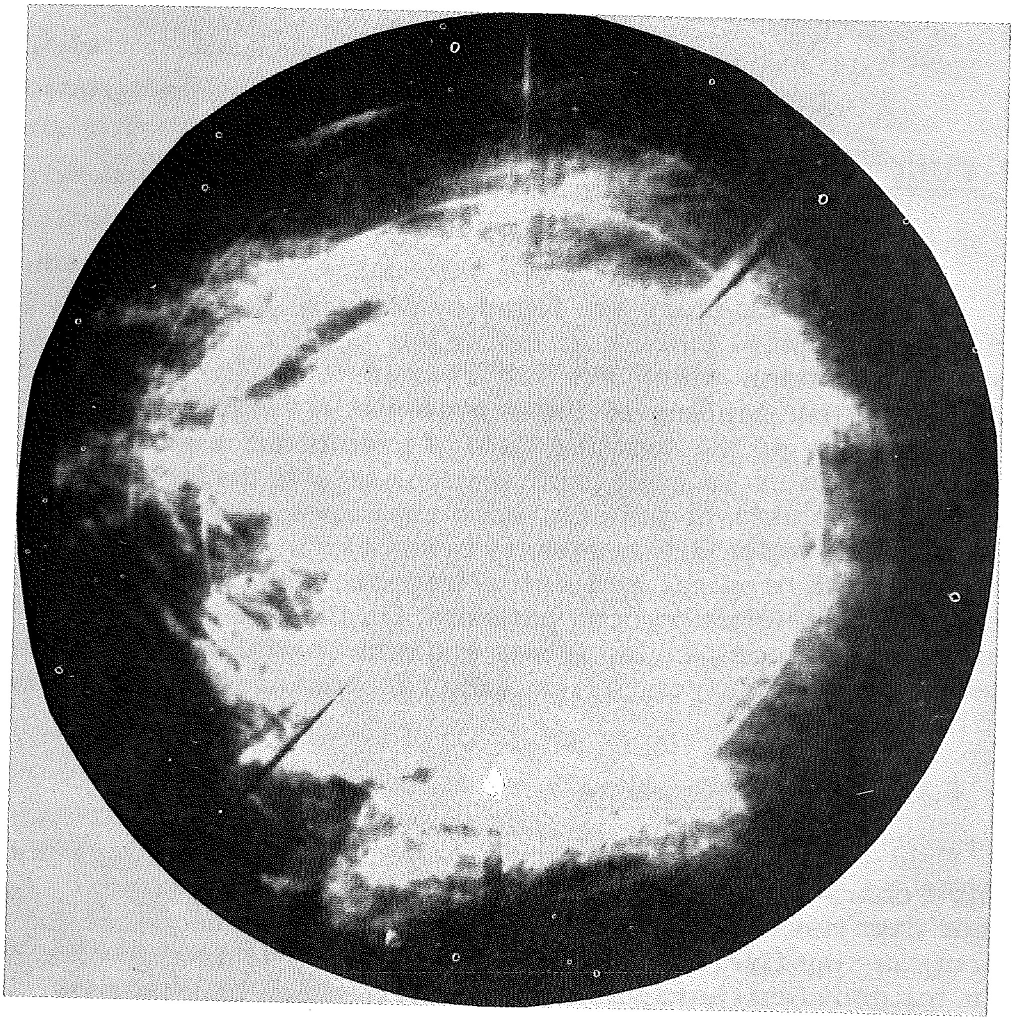


Figure 5-1. CPS-9 PPI During the Early Phase of a Snowstorm. Note Generally Uniform Echo Extending to 150 sm with Slight Banding. AFCRL Blue Hill Radar 25 sm Markers

of irregularly shaped cells with holes essentially echo-free (Figure 5-3). Viewed on the RHI, the patterned echo exhibits a marked change in character. Smooth, featureless echoes gradually increasing in intensity from the top down to 8,000 or 10,000 feet (Figure 5-4) change to a pattern of accentuated tops and more or less vertical cells of higher intensity echo within the overall echo envelope (Fig. 5-5). The transition occurs rather abruptly in most cases and coincides with the region in the storm where

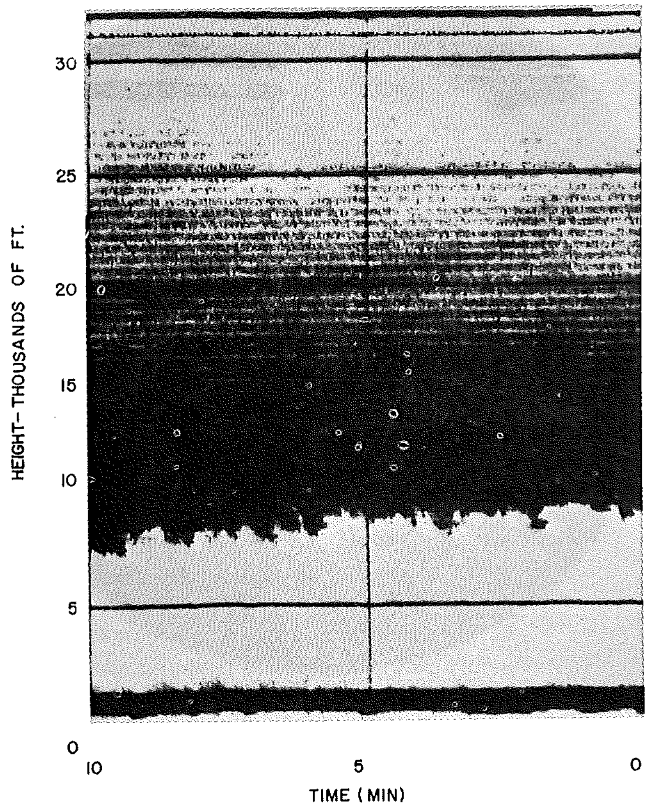


Figure 5-2. AN/TPQ-11 THI Illustrating Lowering of Snow as Storm Advances. Note Downward Protrusions or "Stalactites". A Similar Pattern Can Be Seen on RHI at Short Range, 25 mi. or Less

the precipitation at the ground becomes showery and more variable in intensity than in the earlier part of the storm. As the storm moves away the deep echo weakens or essentially collapses rather abruptly except for perhaps a shallow layer near the ground, where light precipitation may fall out of low clouds for some time, depending on the amount of residual instability behind the storm.

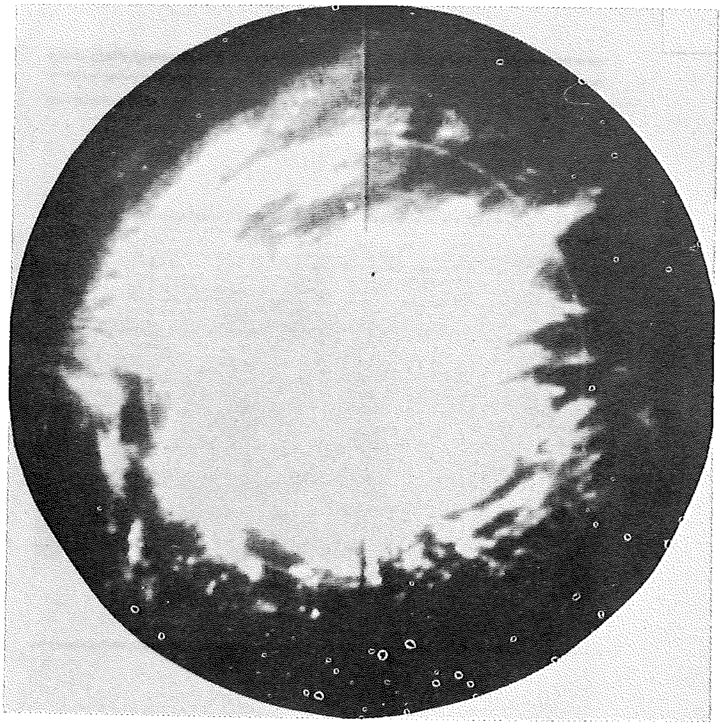


Figure 5-3. CPS-9 PPI During Snowstorm 6 1/2 Hours After Figure 5-1. Note Transition to Patterned Echo in Lower Half of Picture and Echo-Free "Holes". AFCRL Blue Hill Radar 25 sm Markers

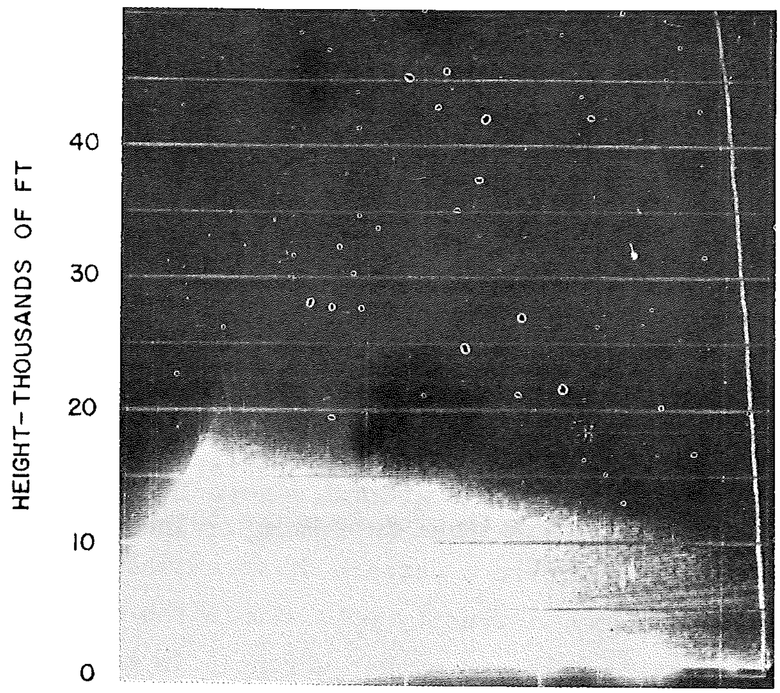


Figure 5-4. CPS-9 RHI During Early Phase of Snowstorm Showing Uniform Echo to 17,000 ft. AFCRL Blue Hill Radar 25 sm Range

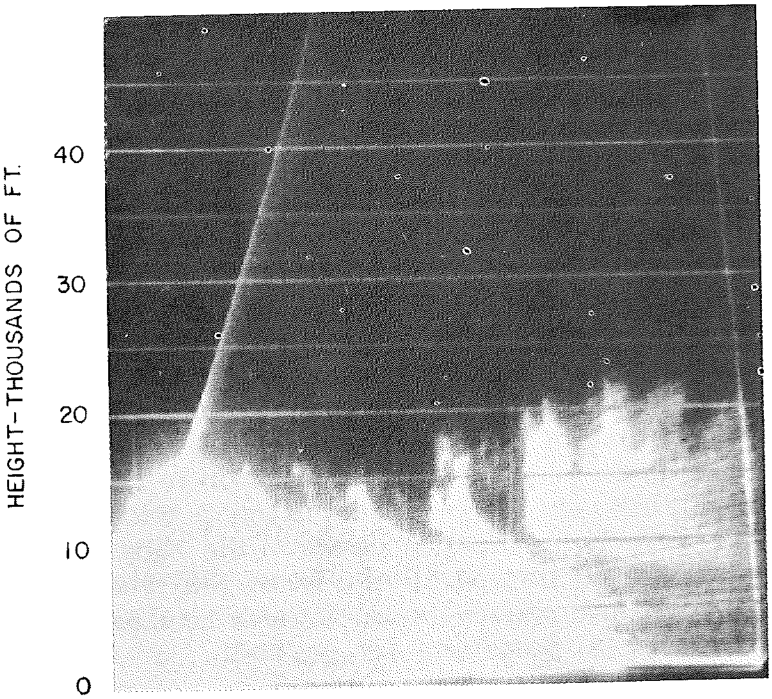


Figure 5-5. CPS-9 RHI During Patterned Echo Phase of Snowstorm at Time of PPI in Figure 5-3. Note vertical High Intensity Echo Cells at Right Center. AFCRL Blue Hill Radar 25 sm Range

5.1.1.2 Summer Cyclones

Summer cyclonic storms, or those of low latitudes in the winter, display a much greater variety of radar echo patterns than do their higher latitude winter counterparts. For the most part, the echo is cellular or convective in character, and shows marked variations in intensity on both the PPI and RHI. In the better developed storm systems, those having a well-organized wind circulation, the precipitation consists of a field to the north of the surface low pressure center, which may contain bands or lines of echo. Frequently there are one or more echo lines to the south of the low pressure center between the warm and cold front, roughly paralleling the latter, but sometimes extending across the warm front. This precipitation frequently has a bright band usually between 12,000 and 15,000 feet depending on the height of the melting level. As a summer cyclonic storm approaches the radar, there may be a sequence on the RHI analogous to the winter case of echo lowering from cirrus level to about 10,000 feet but the precipitation which reaches the radar site is generally derived from a cellular pattern. The end of the precipitation is generally very abrupt. The precipitation echoes in the lines may vary from relatively light intensities to some of the most intense such as those which accompany severe local storms and tornadoes. These will be discussed in detail under Section 5.1.2.2.

5.1.1.3 Fronts

Detailed observation of the field of precipitation, such as those obtainable by radar, immediately reveals a lack of association between fronts and precipitation echo fields. This is to be expected because it has been realized for some time that fronts and frontal surfaces, contrary to the classical frontal model, frequently are not the major lifting mechanism of the production of precipitation. While fronts unquestionably exist, the major role in precipitation production is usually ascribed to vertical motion fields which are present on a wide range of scales. Nevertheless, a marked discrepancy between the radar echo pattern and the current frontal analysis, particularly in the case of a cold front, should cause the forecaster to re-examine the frontal analysis and satisfy himself that the frontal positions are correct.

5.1.1.3.1 Warm Fronts. From the PPI Display

Widespread areas of echoes (as opposed to lines of echoes) commonly occur with warm fronts. A typical approaching warm front usually appears on the PPI scope as a diffuse mass at a distant range, and gradually spreads over a larger and larger area of the scope. The echo is often composed of faint ill-defined bands. As the surface warm front approaches the station, the widespread precipitation echo may cover the center of the PPI scope with relatively uniform intensity. Often, the echo may show some banded structure, not necessarily parallel to the front. With the approach of the surface warm front, the precipitation generally changes somewhat in character, breaking up into showers. The shower cells usually form into bands and move in the same direction as the front.

It should be noted that the echo may be enhanced on the PPI at the range where the beam intersects the melting level. This may cause one to interpret the display as indicating heavier precipitation than is actually occurring. Note also that, with low-powered 10 cm radars operating in a radome there may be considerable attenuation from water on the radome in heavy rain and the signal is thus weakened. Under this circumstance a weak circular echo, centered at the station, may be all that can be seen. This condition does not occur with high-powered 10 cm radars.

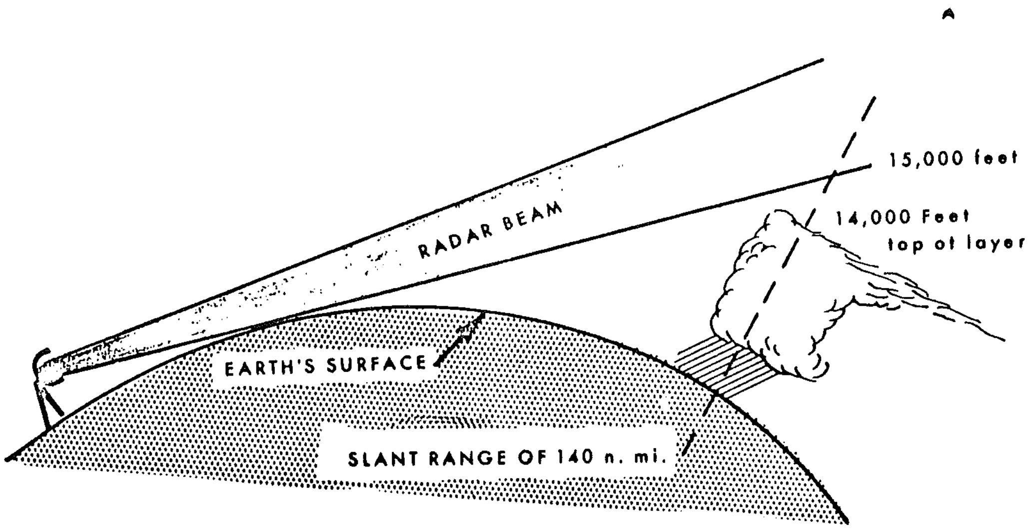


Figure 5-6. Top of Stratiform Precipitation Layer Below Radar Horizon at Extended Range.

From the RHI Display

Ordinarily, the first feature of an approaching warm front observed on the RHI is a clearly defined thick layer aloft.

When first observed, there may be no precipitation reaching the ground, but rain will generally start within a few hours after the layer appears. The layer appears to lower and thicken before the precipitation reaches the ground, especially if the air mass is very stable.

Overrunning precipitation generally appears as a smooth ill-defined mass on the RHI scope. Proper adjustment of the receiver gain will often indicate activity, a bright band, or shear if they are present. Sometimes with stable overrunning, one finds multiple layers aloft. Very careful adjustment of receiver gain may be necessary to observe these layers. Accurate measurement of the heights of the bases and tops of these layers can be made. It is important to remember that the echoes derive from clouds having precipitation-size particles in them and that the heights of bases and tops observed by radar may not agree exactly with visual observations.

On the Forecasting of Stratiform Precipitation

It is sometimes difficult to observe the exact leading edge of stratiform echoes since the echoes are so diffuse. Sometimes, also, stratiform echoes do not noticeably move into an area, but rather form there. If the leading edge of stratiform echoes can be determined, a short-period prediction can be made by simple extrapolation, of the time of beginning of precipitation at the station or other locations in the path of the precipitation.[1] A recent simulated forecast test of the predictability of the edge motion for periods of 2 to 6 hours indicated that in 74% of the trials, the error in timing the arrival of precipitation amounted to 30% or less of the forecast period and that these values changed little as the length of the forecast period was increased.[2] On other occasions, with approaching warm-frontal precipitation, stable-type layers aloft associated with precipitation-bearing clouds of stratiform nature can be seen on the RHI, sloping downward with increasing range. Some have speculated that if the radar antenna is oriented in azimuth such that the slope of the layer is a maximum, the slope of the layer might be projected to the ground as an indicator of the location of the surface front along that azimuth.

In the event that stable-type echoes are observed aloft as described above, the meteorologist should be alert to the fact that light precipitation may begin on the ground an hour or so in advance of the time that the echoes appear on the RHI to reach the ground.

The statement in the forecast of the time of beginning of rain depends on the size of the area for which the forecast is made. For example, a forecast for an airport can be expressed in terms of the nearest hour. On the other hand, a forecast for a large metropolitan area should be expressed in general terms such as late morning, early afternoon, etc. Rain can begin two hours or more sooner on one side of a large metropolitan area than on the other.

Other factors to be considered are (a) whether the flow aloft (generally 850 to 500 mb) will carry the precipitation area into the area for which the forecast is made at the time predicted, and (b) whether the precipitation area is entering a zone of low-level convergence or divergence. For certain synoptic situations, there appears to be some relationship between the location of areas of low-level horizontal convergence or divergence and the location of precipitation echoes, and in some cases the intensity of the two quantities may be related.[3] Upon entering a zone of low-level convergence, the precipitation area will probably tend to persist, other factors, such as the availability of moisture, remaining constant. Upon entering a zone of divergence, the areal extent will probably tend to decrease, other factors remaining constant.

With an approaching "warm front", estimation of the time of beginning of precipitation on the ground at the station (or any other nearby point) must take into consideration the fact that the precipitation detected even at low elevation angles is aloft somewhat, particularly at long ranges, and it may take some time for these drops to hit the ground, if they do so at all.

If a forecast is needed immediately before the precipitation area has had time to move far enough to provide a reliable measurement of velocity, the winds in the layer at the top of the echo will provide a first approximation of the speed of approach of the system unless their direction is at a large angle to the direction in which the echo front is advancing. It is best to wait for about one hour to get two observations of the storm for use in the required calculations.[4]

5.1.1.3.2 Cold Fronts

The precipitation associated with the cold front is also found to occur in a variety of echo patterns -- but usually organized into some sort of a line or narrow band. Some cold fronts are dry and hence will have no associated echo. In others, the echo will be found well in advance of the front itself along a line which coincides with a mesoscale trough. Thus the isobaric trough, which is linked to the vertical motion field, is more closely allied to the precipitation echo than the front itself. If the front and trough coincide, then the radar echo will coincide with the front (Fig. 5-7), otherwise the echo will generally be found in the vicinity of the trough.

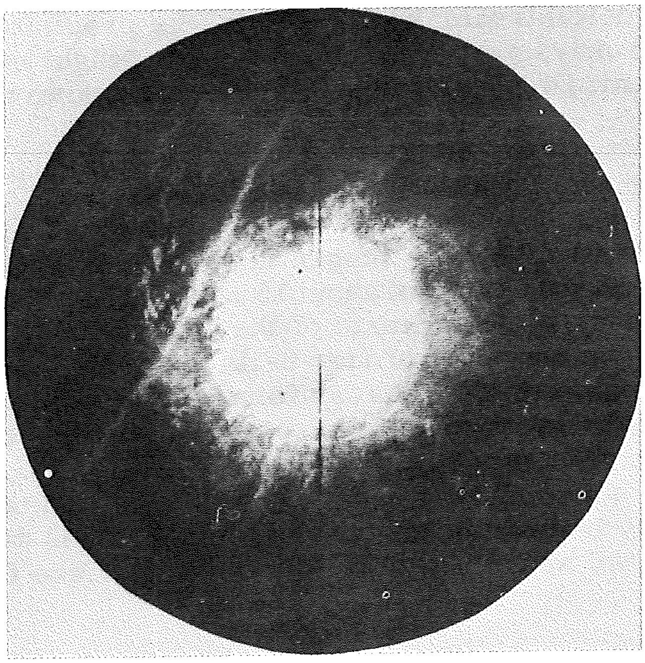


Figure 5-7. CPS-9 PPI Showing Echo Line Embedded in Weak Echo. Cold Front Coincided with Line. [5] AFCRL Blue Hill Radar, 75 sm Range

5.1.1.4 Hurricanes

One of the most valuable services performed by coastal radar installations is the tracking of hurricanes that move within range. The first evidence of an approaching hurricane on the radar is generally the appearance of the outer band which is often in the nature of a squall line some 200 miles from the center. This is a line of heavy precipitation, frequently accompanied by thunderstorms. Between this outer band and the first spiral band of the hurricane there is usually a gap of 50 miles or so without precipitation. The hurricane spiral bands are about 20 miles apart in the outer portions of the storm but near the center of the storm they tend to blend together. Greatest echo heights will be found in some of the most intense cells of the outer band and in the wall cloud surrounding the eye, which is an echo-free area at the storm center (Figures 5-8 & 5-9). The diameter of the eye is normally 10 to 30 miles but may be quite variable. Due to the fact that the rain may not be symmetric around the eye, it may not be possible to locate the center with accuracy from the echo configuration.

Although spiral bands are observed by radar in storms other than hurricanes, they are the characteristic form of echo associated with hurricanes, and provide the forecaster with much useful information. The upwind ends of the spiral bands tend to be concentrated on one side of the hurricane, generally to the right of the direction of motion. PPI observation indicates the precipitation at this end to be in the form of developing cells. This is confirmed by the absence of the bright band on the RHI. Further downstream in the bands, the precipitation becomes more stratiform in character with a bright band or bright region (a broad bright band) present. Dissipation may occur at the downwind end of the band.

5.1.1.4.1 Estimating Wind Speed in Hurricanes

Individual cells tend to move tangentially around the eye. By tracking individual cells for a period of about 15 minutes, either at the end of a band or between bands, an estimate of the hurricane wind may be obtained. Generally an observation of a few cells at approximately the same distance from the center will give sufficient accuracy. Because there may be considerable radial variation of wind speed, observations at about 50 mile intervals from the center may be useful. Because very little vertical wind shear is indicated in hurricanes, echo motions determined by radar may be taken as representative of winds at all levels up to about 20,000 feet with the exception of the surface friction layer.

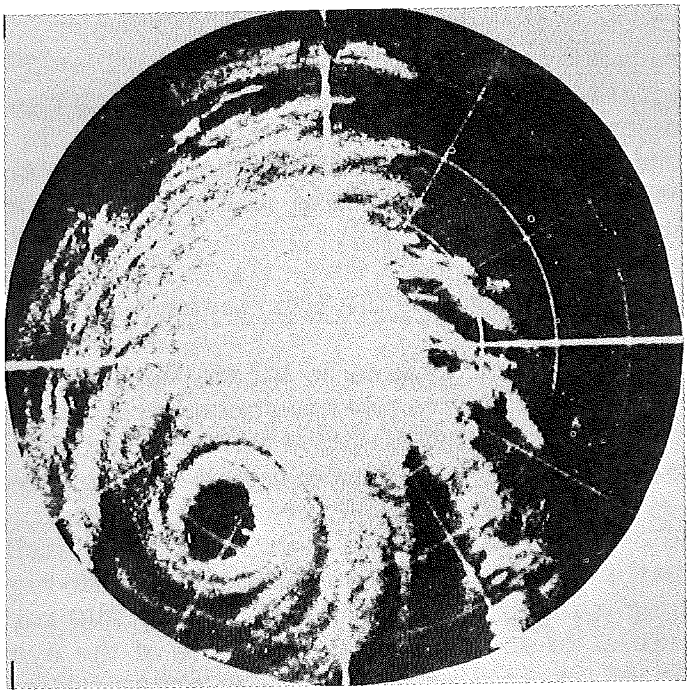


Figure 5-8. SP1M(10 cm) PPI of Hurricane Helene Showing Echo-Free Eye, Wall Cloud Surrounding Eye and Spiral Bands. U.S. Weather Bureau Radar at Cape Hatteras, 20 n. mi. Markers.

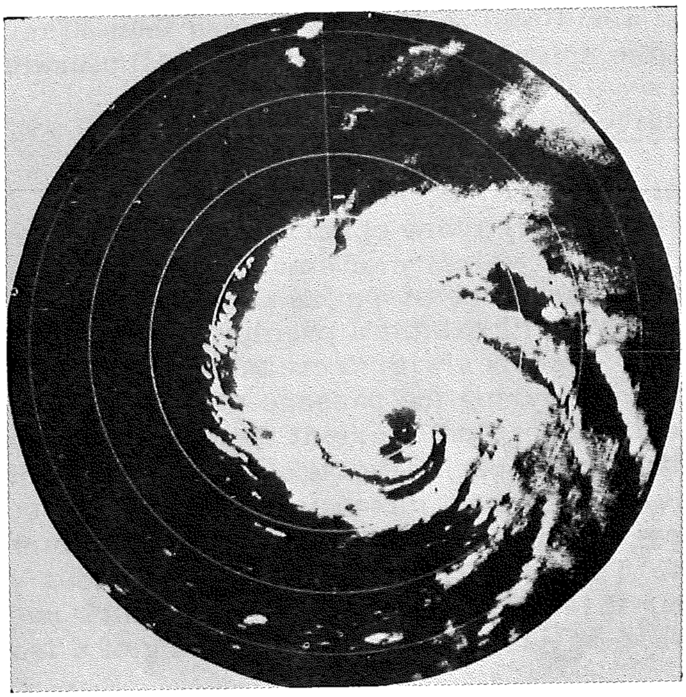


Figure 5-9. WSR-57 PPI of Hurricane Cleo, a Small Northward-Moving Hurricane. U.S. Weather Bureau Radar, Miami, Florida, 100 n. mi. Markers.

5.1.1.4.2 Motion of Hurricanes

The most reliable feature of the hurricane which can be tracked to provide the direction and speed of the storm is the eye. In addition some idea of the direction of motion may be gained if the upwind ends of the bands can be observed because these are usually to the right of the direction of motion.

5.1.1.4.3 Locating the Eye of the Hurricane

It is of considerable importance to locate the eye of the hurricane. Conventional meteorological data over the ocean are generally infrequent and insufficient to determine the position with reasonable accuract. The best method is undoubtedly a radar fix of a well-defined eye, surrounded bq precipitation echoes on all sides. However, a well defined eye is not always detectable by radar due to an unsymmetrical distribution of precipitation, as usually occurs when hurricanes move into higher latitudes. In addition, at long ranges, beyond about 175 to 200 miles, the eye is frequently not visible. In such cases the position of the eye may be estimated by the use of a spiral overlay.[6] The precipitation bands are in the shape of equiangular spirals which cross the hurricane isobars at angles varying from 10° to 20°. The use of an angle of 15° for the overlay has been found to be sufficiently accurate for most purposes. The overlay is adjusted manually so as to fit a portion of a well-defined spiral band. After a satisfactoy fit has been obtained, the position of the center is indicated on the overlay (Fig. 5-10). Although this method may give a location which is sometimes in error by more than 30 miles (depending on the portion of the spiral band visible) it is still a useful observation.

5.1.1.5 Easterly Wave

Tropical storms usually develop in easterly waves. Active easterly waves should be kept under close observation. When easterly wave patterns are observed, the velocity of small precipitation elements at as many different locations in the storm as possible should be determined. True tropical cyclones will exhibit a precipitation element velocity pattern in which speed increases with decreasing distance from the center of rotation. Frequently during the passage of easterly waves across the radar scope, the hard core cells orient themselves in circular formations rotating about an apparent vortex. This center of vortex is, as a rule, free of echoes. Sometimes, this presentation takes the form of spiral bands, and suggests the formation of a vortex of an embryonic hurricane circulation. This requires close and continuous observation to determine whether it is merely a transient eddy which may disappear in a few hours or whether it is actually the beginning of a tropical cyclone.

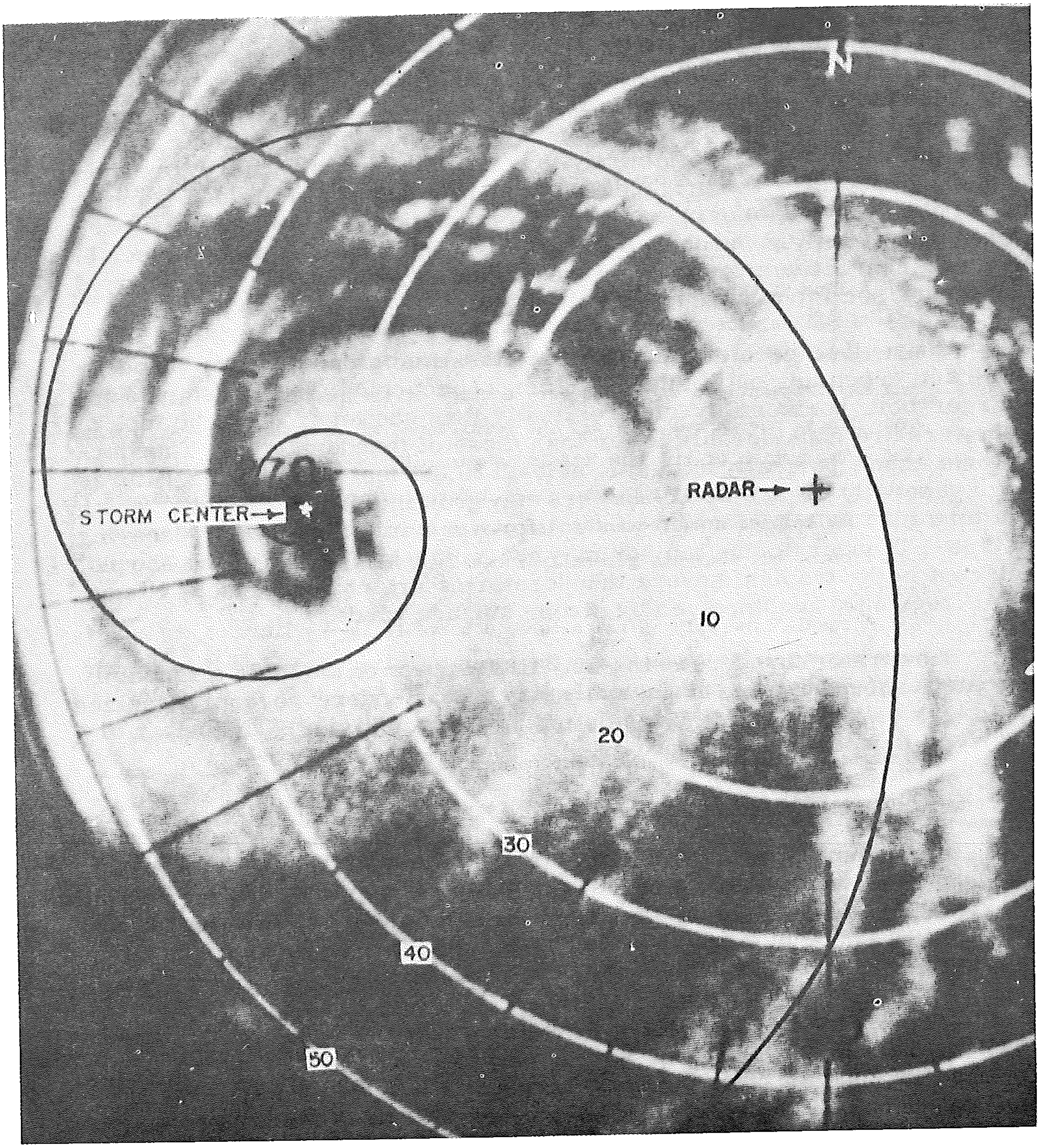


Figure 5-10. SP1M (10 cm) PPI of Hurricane Connie Demonstrating Use of 15° Spiral Overlay as an Aid in Locating Storm Center. U.S. Weather Bureau Radar at Cape Hatteras, 10 n. mi. Markers.

5.1.2 Mesoscale Systems

5.1.2.1 Convective Precipitation and Thunderstorms

Convective precipitation is readily differentiated from stratiform on a radar. Convective precipitation is characterized by cellular echoes with generally higher reflectivity than echoes from stratiform precipitation. In addition, the bright band, which is a characteristic of the melting layer in stratiform precipitation, is not apparent in convective precipitation except in the decaying stages. The vertical velocities associated with convective precipitation are of the order of 1 m/sec as compared to 10 cm/sec for stratiform precipitation.

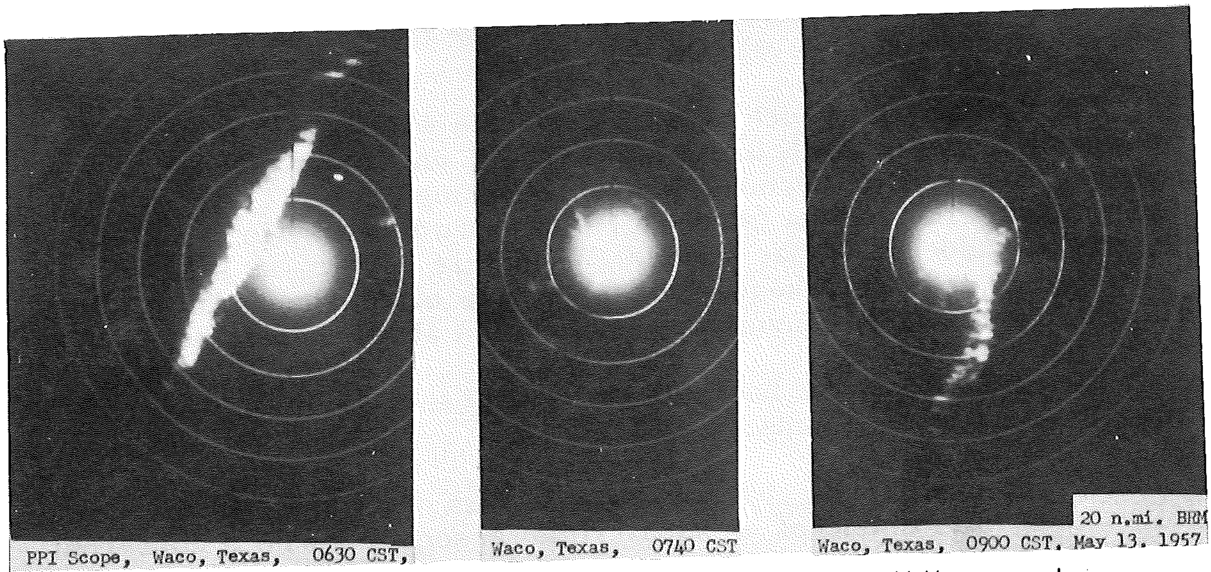
Convective precipitation may be classified as showers or thunderstorms, depending on whether lightning is occurring. Thunderstorms are larger both horizontally and vertically than showers. The echo tops of showers are considerably lower than those of thunderstorms. Thunderstorm echos generally extend to at least 20,000 feet where temperatures are generally below -22°C. Showers may grow into thunderstorms, which in turn may be transformed to stratiform precipitation in their decaying stages. Thunderstorms may or may not contain hail reaching the ground. Except in the tropics, severe thunderstorms are characterized by large hail frequently accompanied by strong surface winds.

Showers or thunderstorms may first appear on the PPI as randomly located echoes but they subsequently may have a tendency to form organized clusters or lines. The line formation is characteristic of the better organized thunderstorm situations.

5.1.2.2 Squall Lines

It does not appear possible to establish a unique "squall line" model, or a unique radar "cold front" model. Either phenomenon may exhibit certain characteristics of the other. Both, however, are characterized on the PPI scope by having their echoes arrayed in lines, the lines being comprised of isolated or massed convective echoes.

The Thunderstorm Project[7] found that in a "squall line" there is usually a zone of convective activity comprising several lines and, although the zone may persist for a considerable period of time, the lines within it are constantly undergoing change - new lines forming and older ones dissipating. A very intense line lasted for eleven hours. Weak ones lasted less than two hours.



Squall line approaching.

Squall line over station, echo line not shown due to attenuation.

Squall line moving away; echo line reappearing on radar.

Figure 5-11. *Loss of Echo Presentation on WSR-1 Radar During Squall Line Passage.*

Squall lines are most intense in the late afternoon and evening. Sometimes, re-intensification occurs during the late evening or early morning.

Midwestern squall lines possess some of the most violent local weather observed in nature. Combinations of strong and gusty winds, large hailstones, and tornadoes accompany squall lines especially during the spring and summer months. Cloud tops may build to heights in excess of 60,000 feet in well-developed systems.

When heavy rain, such as accompanies a well-developed echo line, occurs at a station with a low-powered 10 cm. radar or with a 3 cm. radar, the resulting attenuation with resulting loss of range and echo penetration, will give the false impression of a decrease in the intensity or nonexistance of radar echoes. When this occurs, as shown in the following photographic sequence, assistance of nearby radar stations should be requested in furnishing information about echoes.

The following have been noted from observations of squall lines associated with cold fronts: 8

(1) the local winds aloft are not useful in estimating the direction of movement of a squall line associated with a cold front.

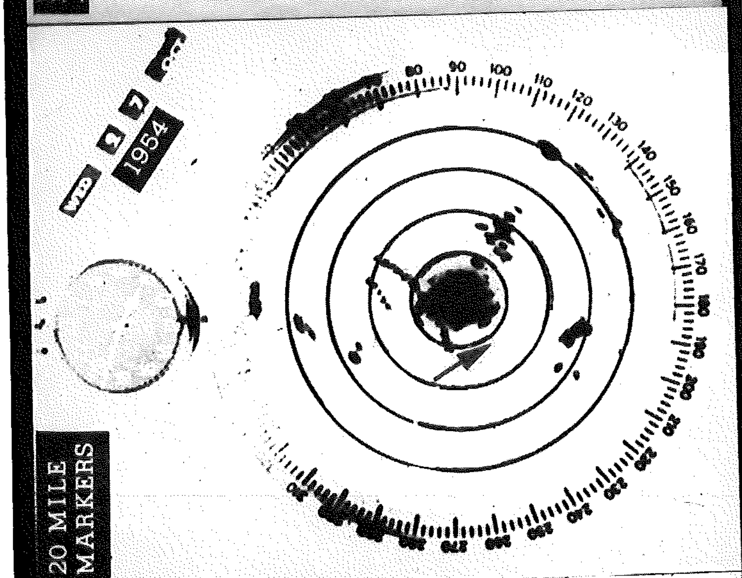
(2) The movement of individual echoes does not indicate the movement of a squall line associated with a cold front.

(3) The movement of a squall line associated with a cold front can be determined by observation of the advance of the leading edge of the disturbance.

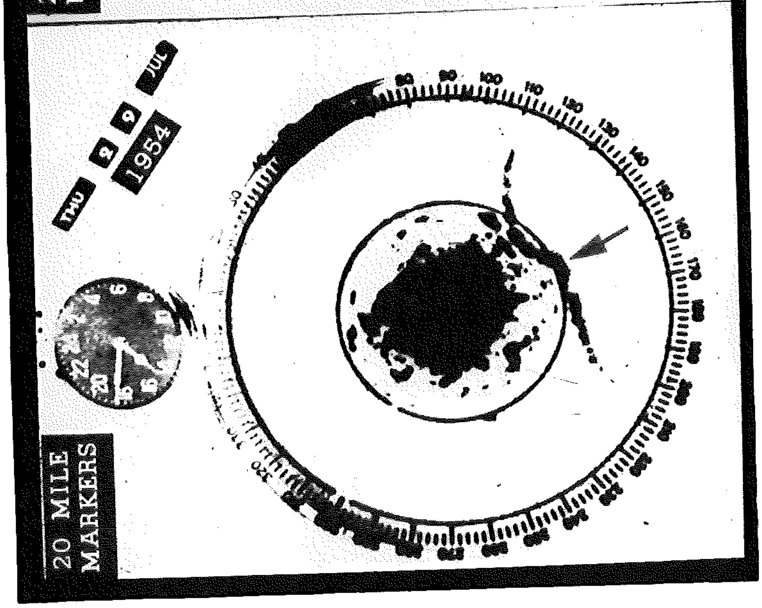
(4) Squall lines are frequently associated with and parallel to advancing cold fronts but they are generally located a few hundred miles ahead of the fronts.

The first indications of a squall line during the day are usually visual, i.e., cumulus clouds arrayed in a line. From 15 minutes to an hour later as the cumulus clouds grow, the radar will begin to display echoes. Generally, the first indication of a squall line on the PPI scope is the observance of a few widely separated echoes in a line. As more echoes form, they fill in the spaces to make the line more evident. Commonly a number of thunderstorm cells develop within half an hour along a line many miles in length. Once formed, the squall line is maintained by continuous development of new echoes to replace those that dissipate. A well-developed squall line may be continuous over a distance of several hundred miles.

Cloudless Wind Shift Line, Cape Hatteras, N. C.



"Norther" Cloudless Wind Shift Line, Victoria, Texas



Cloudless Wind Shift Line, Victoria, Texas

Cloudless Wind Shift Line

On occasions, radar has been able to detect weak, narrow line echoes that are associated with the passage of a cloudless wind shift line and accompanying "pressure jump" at the station. The echoes from these wind shift lines appear to derive from discontinuities of moisture, temperature and pressure (and consequently of index of refraction) which accompany such phenomena. The greatest distance from the station that these line echoes have been observed is 100 miles and they are seen at long range best by powerful, sensitive radars. They may occasionally be seen with low-powered radars but then only at short range.

The illustration on the left shows a warm, moist air mass moving inland from the Gulf of Mexico. (The direction of movement is shown by the white arrow.) When the line passed the station, the wind shifted from SSW 18 to SSE 21 + 26. This phenomenon has been observed many times and is often referred to as a sea-breeze front. No pressure jump was recorded in this case.

The middle illustration is a PPI picture of a "dry 'norther'" in Texas. The echo of the wind-shift line is across the northwest part of the ground pattern. The wind shifted from NE to NNW 21 + 24, as the echo passed. In this case a pressure jump occurred.

The illustration on the right shows the PPI scope at Cape Hatteras, N. C., on an occasion when definite association of the line echo and a well-defined pressure jump line was observed.

Our understanding of this phenomenon is still incomplete. The wind shift or pressure-jump line is apparently detected by radar owing to reflection from the refractive index gradient which accompanies such phenomena, but not all such occurrences are detected because the gradients involved are not sufficient.

5.1.2.3 Tornadoes and Other Severe Local Storms

Radar observations may often furnish an indication as to the possible formation or presence of severe storms. Some of the radar indicators which may be recognized as characteristic of severe storms are summarized in the following:

5.1.2.3.1 Wave Pattern

Many severe storms and tornadoes have been found to develop near line echo wave patterns (LEWP) (Fig. 5-12). A LEWP has been defined as

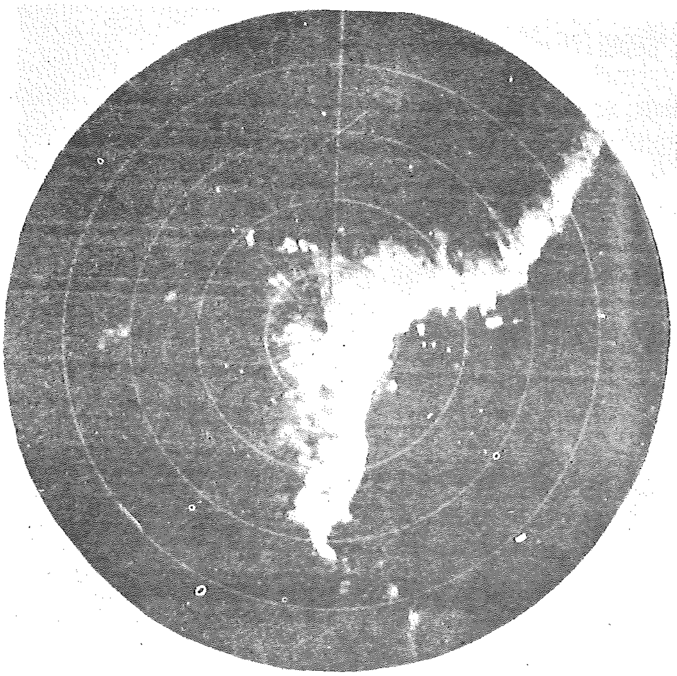


Figure 5-12. WSR-57 (10 cm) PPI of a Line Echo Wave Pattern (LEWP) in a Squall Line. U.S. Weather Bureau Radar, St. Louis, Missouri, 50 n. mi. Range, 33 db Attenuation.

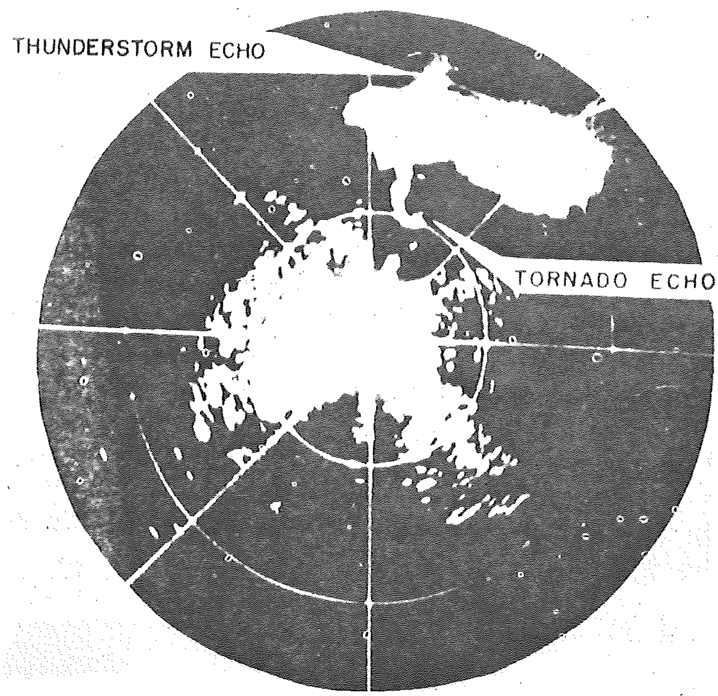


Figure 5-13. APS-15 (3 cm) PPI of Classical Tornado "Hook" Patterns Illinois State Water Survey Radar. 10 sm Markers. [9]

"a configuration of radar echoes in which a line of echoes has been subjected to an acceleration along one portion and/or a deceleration along that portion immediately adjacent, with a resulting sinusoidal mesoscale wave pattern in the line."[10] However, the presence of such irregularities do not necessarily indicate that a severe storm is imminent. In addition the observation of a wave pattern depends on the radar characteristics and range effects so that it is of limited forecasting value.

5.1.2.3.2 Hooks, Fingers

Many tornadoes have been found to be associated with a characteristic hook or "figure 6" attached to the upwind side of an echo complex which may form part of a line. In some cases the hook is a portion of a noticeable spiral pattern emanating from the main echo (Fig. 5-13).

Protruding fingers from a large thunderstorm echo (Fig. 5-14), generally on the upwind side, have been found to be associated with hail a half inch or more in diameter. These fingers are believed to be hail shafts on the fringes of the storm.

Both hooks and fingers have been observed which were evidently not associated with severe weather of any kind. In addition, many tornadoes have been observed without the characteristic hook, and hail certainly occurs without fingers. These hooks are referred to as false hooks. The observation of these features depends on the range, on the beam width of the radar, on attenuation and on the angle of view of the radar. For instance a hook may be observed at 10 cm but may not be observed at 3 cm because of attenuation as indicated by the V-shaped notch on the far side of a large thunderstorm echo.

A bona fide hook formation has the following distinctive features:[11]

(1) The hook is located in the trailing half of the main echo with respect to its motion and occurs most often in the right rear quadrant.

(2) The hook is formed by a cyclonic swirl of a part of the main echo into a hook-shaped appendage.

(3) The hook is a small scale feature having a dimension of about 10 n. mi. or less from the main body of the echo to the farthest extremity of the hook.

(4) On occasions the hook has preceded the formation of a tornado. (Reported as almost an hour in the case of the El Dorado tornado of June 10, 1958.)

(5) The few RHI cross-sections that have been measured through a hook show it to extend as high as 35,000 - 40,000 ft. Thus it appears to be the echo from a high level vortex.

(6) The hook forms in a short time; usually, only a few minutes are required.

(7) The duration of an identifiable hook varies greatly, from a few minutes to an hour, or even more in some cases. The fluctuations in the hook display, from clear-cut to indistinct, appear to be related to corresponding vigor of the tornado and width of its track; thus a crisp, clear hook appears to be related to a narrow funnel with an unmistakably clear track on the ground whereas a large diffuse hook may be associated with a funnel aloft or with a wide and more diffuse damage path on the ground. Many more observations are needed to confirm these speculations, however.

5.1.2.3.3 Echo Convergence, "V" Notches

A number of investigators in areas such as New England and Kansas, have reported tornado development where separate thunderstorm echoes, moving at different speeds and directions, merge into a single larger echo mass. Many of these echo mergers appear to have been associated with unusually high echo speed, exceeding 40 knots. The tornado development appears to occur at a V notch (see arrow of Fig. 5-15), not caused by attenuation, in the region of junction of the two echoes. However, frequent echo convergence has been observed in Florida without tornado development, although heavy rain usually ensued.

5.1.2.3.4 Echo Top Criteria

Hailstorms generally have higher echo tops than ordinary thunderstorms. In a survey of hailstorms it has been found that the probability of hail in the New England area is zero for echo tops at 20,000 feet and the probability of hail rises to 48% at heights above 50,000 feet.[12] Median echo tops for hailstorms are about 43,000 feet as compared to 30,000 feet for ordinary thunderstorms. However, there is considerable variation from region to region. For instance in the high plains of Alberta and in Colorado, hail occurs with echo tops about 10,000 feet lower than in New England, while in Texas echo tops in hailstorms are higher than in New England. Evidently the height of the echo tops in relation to the tropopause is a better criterion for the existence of hail. Most hailstorms have been found to penetrate into the stratosphere.

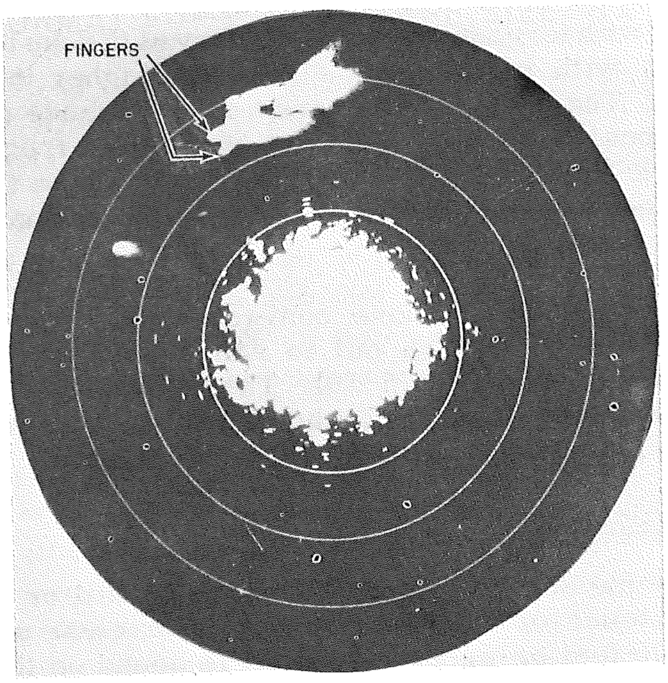


Figure 5-14. WSR-57 (10 cm) PPI Showing Intense Thunderstorm Echo NNW of Radar Site and Characteristic "Fingers" Usually Associated With Hail. U.S. Weather Bureau Radar, Kansas City, Missouri. 100 n. mi. Range.

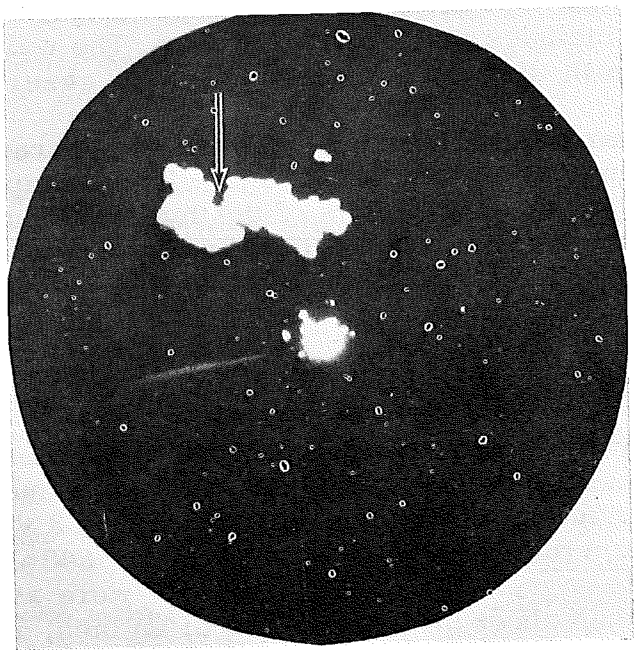


Figure 5-15. AN/FPS-77 (5.4 cm) PPI Showing V Notches Resulting from Recent Merger of Two Thunderstorm Echoes. A Severe Hail and Windstorm Occurred at Location Indicated by Arrow. AWS Radar, Hanscom Field (Mass.) 30 n. mi. Range, 5° Elevation.

Thunderstorms with tornadoes often have very high echo tops, generally above 50,000 feet, with many storms reaching higher than 60,000 feet (See Section 4-3). The greatest frequency of tropopause penetration by thunderstorms appear to be near the area of greatest frequency of tornadoes and severe thunderstorms. A penetration above the tropopause by about 10,000 feet is considered to be a good indication of a tornado-producing thunderstorm complex.[13]

Narrow spikes extending above convective echoes have been observed on some WSR-57 radars out to ranges of about 80 miles thus giving spurious echo tops[14] (Fig. 5-16). They are evidently the effect of side lobes directed towards intense echoes, and are believed by some to be associated with hail shafts in intense thunderstorms.

5.1.2.3.5 Vertical Echo Structure

Analysis of some severe thunderstorms with hail or tornadoes has indicated the existence of an echo free vault or clear space from the ground up to 25,000 feet or higher. The vault is bound on the upwind side by a vertical wall echo extending down to the ground and on the downwind side by an echo overhang extending down several thousand feet (Fig. 5-17).[15] This vault lies almost directly below the highest echo top. Farther downwind beyond the overhang is the anvil cloud. From this type of structure a model of airflow in a severe storm was deduced by Browning and Ludlam, who suggested that the vault is the most intense portion of the updraft which also includes the overhang region. The wall echo is evidently associated with the tornado hook echo as observed on a PPI.

These features are best observed at relatively short range (less than about 50 miles) and with a narrow beam radar. It also requires detailed RHI observations at different azimuths of the thunderstorm complex and a discerning eye to comprehend the three dimensional structure of the pattern. Hence, attempts to identify severe storms by these features may be rather difficult.

5.1.2.3.6 Reflectivity Criteria

The reflectivity of thunderstorms generally increases with the severity of the storm. Hail is usually associated with the most intense portion of the echo. A value of Z greater than about 3×10^5 mm^6/m^3 as observed with 10 cm radar has been found to be almost always associated with hail; Z values greater than 10^6 mm^6/m^3 were associated with large hail, greater than about three-quarters of an inch, and tornadoes. With 3.2 cm radar peak values of Z in hailstorms range from 3×10^4 to 6×10^5 mm^6/m^3, considerably lower than at 10 cm. The difference may

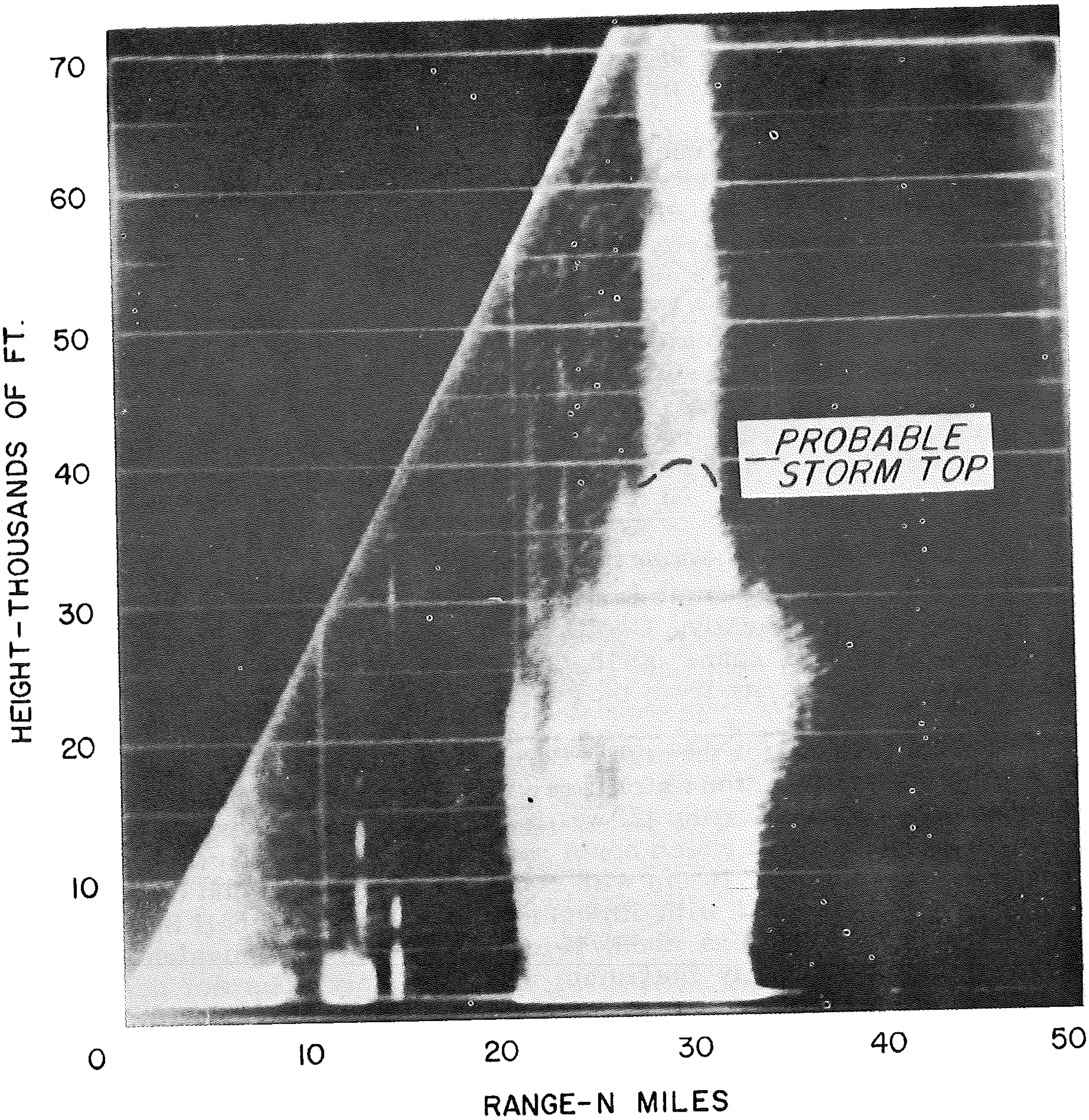


Figure 5-16. WSR-57 (10 cm) RHI of Thunderstorm Showing Spurious Storm Top to More Than 70,000 ft., an Effect of Side Lobes. Weaker Side Lobe Echoes Can Be Seen at About 21 and 23 n. mi.[16] U.S. Weather Bureau Radar, St. Louis, Missouri.

be due partially to attenuation and partially to the reflectivity characteristics of large wet hail. With 5.4 cm radar the criteria for hailstorms is estimated to be a value of Z exceeding 8×10^4 mm^6/m^3 and for tornadoes about 3×10^5 mm^6/m^3.

The vertical echo structure as observed at 3 cm may give some indication of storm severity. Donaldson,[17] who analyzed storm cross sections synthesized from PPI scans at different elevation angles, found that the maximum reflectivity aloft is a notable feature of severe storms (Fig. 5-18). For ordinary thunderstorms (without hail at the ground), Donaldson found the reflectivity is nearly constant, up to about 15,000 feet with Z less than 10^5 mm^6/m^3; above that level there is a relatively rapid decrease. As storm severity increases reflectivities increase, and there is a tendency for a maximum reflectivity to occur near 20,000 feet. For thunderstorms with large hail the maximum at 20,000 feet is about 6 db greater than at 5,000 feet, while for tornadoes it is about 8.5 db greater.

Few if any observations of the maximum reflectivity aloft have been reported with RHI type scans and it has not been observed with 5.4 cm or 10 cm radar. Specifically, Geotis[18] at M.I.T., in the same area as Donaldson, used RHI scans of 10 cm and 3 cm radars and found little change in the reflectivity from the ground to about 15,000 or 20,000 feet.

Possible reasons for the high reflectivity aloft reported by Donaldson include (1) 3 cm attenuation which is greatest at low levels and decreases at higher angles of elevation (2) wetting of large hailstones as they fall below about 20,000 feet which could cause a reduction in reflectivity at 3 cm but not at 5.4 or 10 cm with consistent sized hail and (3) water-coated spongy hail aloft with dimensions approximately half the wavelength, which backscatters about twice the energy of equivalent water spheres. The reflectivity maximum aloft probably does not occur at 5.4 cm or 10 cm.

5.1.2.3.7 Summary of Severe Storm Criteria

According to Donaldson [19] an observation of any one of the following conditions indicates the possibility of severe storm development:

1. Echoes are in a line with a wave pattern (LEWP).

2. Echoes are noticeably converging.

3. Echo speeds exceed 40 knots.

4. Echo edges are sharply indented or scalloped.

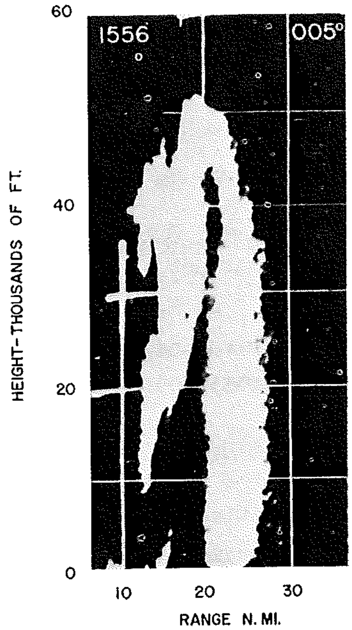


Figure 5-17. FPS-6 (10 cm) RHI of a Severe Thunderstorm Showing an Echo-Free Vault to About 44,000 ft.[16] ADC Tinker AFB Radar, 38 db Attenuation.

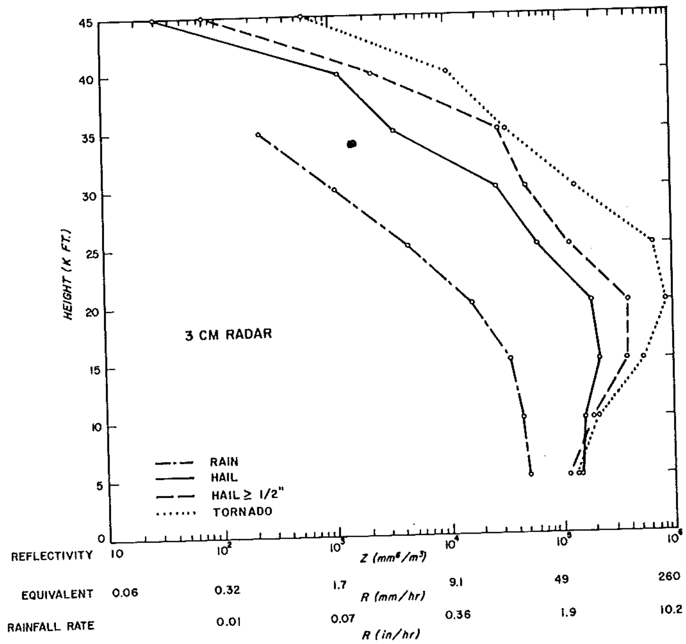


Figure 5-18. Reflectivity Criteria for Different Classes of Storms, after Donaldson[17] Note Maximum Aloft for Hail and Tornado Cases

5. Echo tops penetrate the tropopause.

6. 10 cm radar reflectivity exceeds 3×10^5 mm^6/m^3 anywhere in the storm.*

7. 3 cm radar reflectivity exceeds 10^4 mm^6/m^3 at 30,000 feet.

8. A 3 cm radar reflectivity maximum persists above the 0°C level.

The actual presence of a severe storm may be indicated when any of the following conditions are observed:

1. The characteristic tornado hook appears on PPI scan at low altitudes (Figure 5-13).

2. Echo tops penetrate the tropopause by 10,000 feet or more.

3. 10 cm radar reflectivity exceeds 10^6 mm^6/m^3.**

4. 3 cm radar reflectivity exceeds 10^5 mm^6/m^3 at 30,000 feet.

5. A 3 cm radar reflectivity maximum persists at 20,000 feet or higher having at least twice the magnitude of the reflectivity at the 0°C level.

6. A persistent vault-wall structure is observed on RHI scan beneath the highest echo top (Figure 5-17).

Severe storm warnings to points downwind of the location of any of these conditions are probably justified.

5.1.3 Angels [20, 21]

Angels are radar echoes from invisible targets. They are most readily observed on the A-scope of a vertically directed radar; occasionally they are observed on RHI or PPI indicators. In addition, there is considerable variation in their frequency of occurrence with respect to geographical location. For example, their frequency of occurrence in the Midwest is greater than in the New England area.

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* For 5.4 cm the criterion is estimated to be 8×10^4 mm^6/m^3.
** For 5.4 cm the criterion is estimated to be 3×10^5 mm^6/m^3.

5.1.3.1 Point Angels Viewed Vertically

On a time height record of a vertically directed radar, angels frequently appear as point-targets (elongated on the height scale) with their number generally decreasing with height (Fig. 5-19). They have been observed with different wavelengths from 0.86 to 23 cm. The maximum observed height is 27,000 feet. The echoes are coherent (i.e., nonfluctuating) and apparently drift with the wind, and so remain within a stationary beam for a period of the order of one to several seconds depending on the width of the radar beam and the wind speed. For a 0.86 cm vertical radar (AN/TPQ-11) with a 0.3° beam a typical duration of a point angel is two seconds, at 3.2 cm with a 1.0° beam, the duration of the same angel passing through the beam would be about seven seconds.

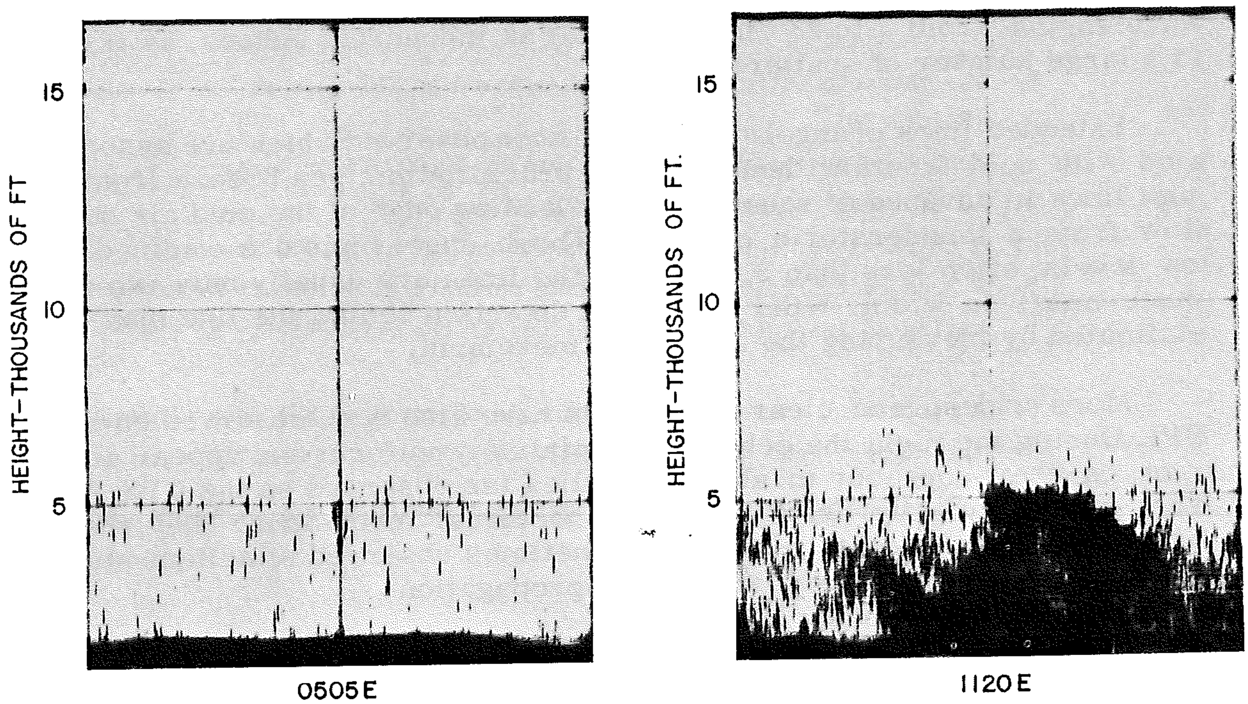


Figure 5-19. AN/TPQ-11 (0.86 cm) THI Record of Point Angels on 9 June 1962. Note Diurnal Increase in Angel Activity Between 0505E and 1120E. No Clouds Below the Cirrus Level. Vertical Lines at 5 Min. Intervals. AWS Radar, Hanscom Field (Mass.)

Although point angels frequently appear to have a random distribution with height, they are occasionally observed to be concentrated in an apparent line or band over a small height interval. These lines are almost invariably found to be located at or near the base of elevated temperature inversions, as determined from radiosonde data. On some occasions no angels or perhaps a few scattered ones are observed above the inversion. Hence, the observation of an angel line or band is good evidence that an inversion exists at the indicated level. Unfortunately, the absence of an angel line does not necessarily indicate that no inversion exists, because even during intense inversions angel lines may not be observed.

5.1.3.2 Angels on PPI

Angel echoes are observed on the PPI less frequently than on the indicators of vertically directed radars. They have been observed at wavelengths from 3 to 23 cm and appear as incoherent echoes, as if due to a large number of scatterers.

Extended lines of angel echoes have been observed which are associated with cold fronts without cloud or precipitation, sea breeze fronts, gust lines in advance of squall lines and leading edge of the cold air outflow from a thunderstorm complex. These angel lines are confined to low levels, often less than 5,000 feet. The lines are usually only two or three miles in width. Wind speed and direction behind the line may be estimated by measuring the angel line movement.

More widespread clear sky echoes have also been observed on the PPI. During the night the echoes are relatively uniform and appear as a haze on the scope out to about 50 miles (as observed on the CPS-9). They are apparently associated with nocturnal inversions. They show little structure or pattern and are sometimes observed simultaneously with echoes resulting from anomalous propagation.

During the day the echoes have a weak cellular structure (Fig. 5-20) and appear to be associated with convective activity. Their maximum range on the CPS-9 is about 85 miles. On occasion the angel cells have a relatively uniform size distribution in the morning and then become larger and more variable in the afternoon. This behavior is very similar to that of cumulus clouds in some regions, and is part of the evidence indicating that the angels are associated with convective activity. On other occasions the echoes consist of parallel bands, resembling "cloud streets."

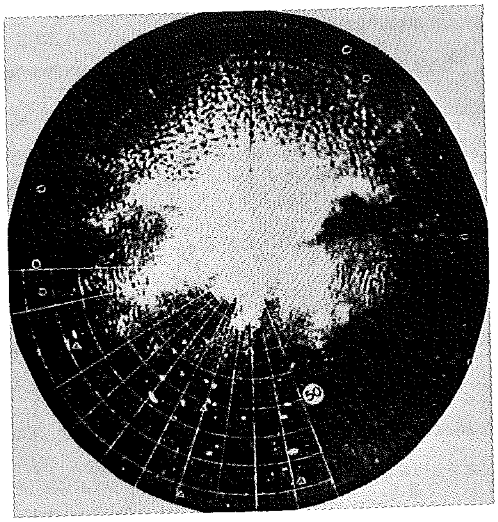


Figure 5-20. CPS-9 PPI Showing Cellular Type Angel Echoes on a Cloudless Day Detectable to Ranges of 85 sm to the NE.[22] AWS Radar Schilling AFB (Kansas) 10 sm Range Markers.

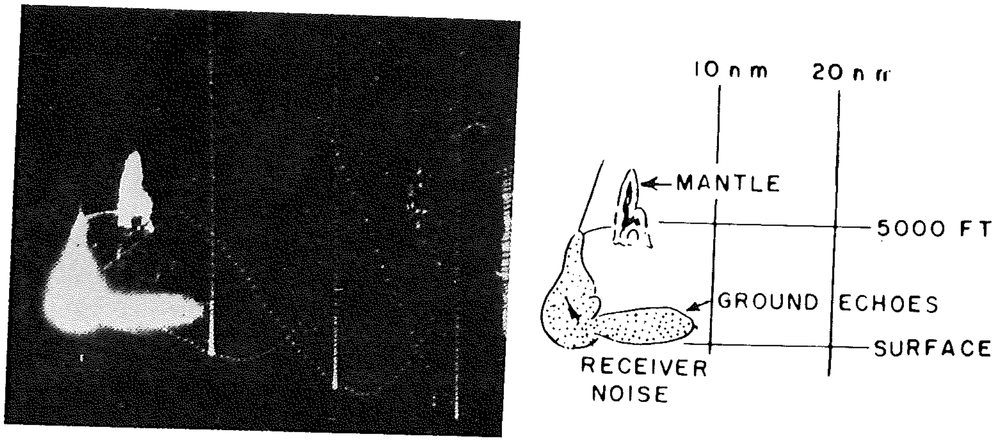
5.1.3.3 Angels on RHI

Occasionally layers of angels have been observed on the RHI that extend out to distances up to 17 miles from the radar. These angels are located at heights coinciding approximately with those of inversions. Sometimes multiple lines are observed; as many as five have been noted. These multiple lines appear to be associated with a complex or multiple inversion structure. When viewed obliquely these angel lines appear to be incoherent but increased coherency is noted as the elevation angle of the antenna is increased.

Incoherent echoes coinciding with the outer boundaries of cumulus clouds have also been observed. These have been called "mantle" echoes (Fig. 5-21) and are very infrequently observed, possibly because of their small size. They have an inverted U or V-shaped appearance. Only the upper boundaries of the cloud are observed so that the radar is evidently not detecting the water drops associated with the cloud.

5.1.3.4 Explanation of Angels

The following explanations of angels have been offered: (1) birds and/ or insects and (2) refractive index discontinuities.



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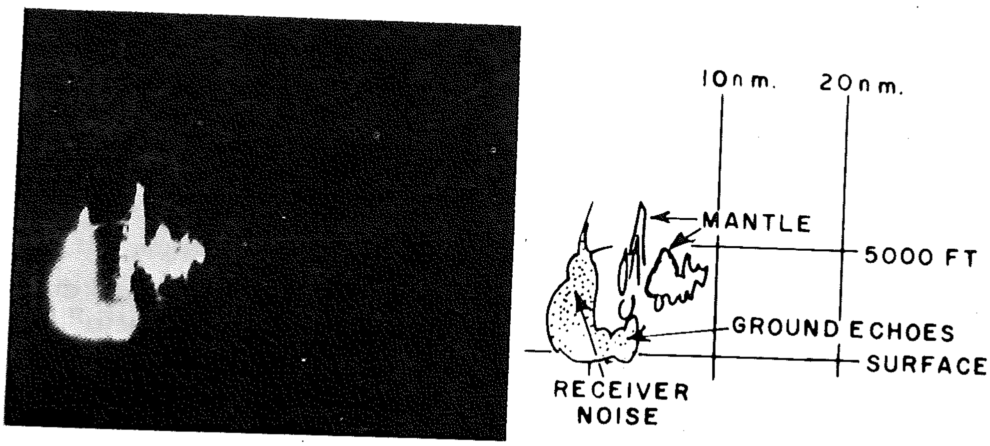

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Figure 5-21. FPS-6 (10 cm) RHI of Cumulus Mantle Echoes at Close Range and Explanatory Diagram at Right. [23] M.I.T. Lincoln Lab Radar, S. Truro, Mass.

There is no doubt that birds or insects can be observed by radar. Birds and insects have been observed by aircraft as high as 14,000 feet. These are considered to comprise the vast majority of coherent echoes.

Refractive index discontinuities are sharp changes in water vapor and temperature over short distances. For detection, according to theory, there must be a substantial change in the refractive index over a distance that is small compared to the radar wavelength. Such a discontinuity occurring within a distance of less than 1 cm is difficult to visualize and even more difficult to measure. Nevertheless it is the opinion of some radar meteorologists that many angels must be associated with such discontinuities, particularly those associated with atmospheric turbulence.

5.2 FUNCTION IN FORECASTING

5.2.1 Forecasting of Cell Echo Motion

The motion of single-celled echoes or small clusters of cells that are resolved as a single cell on the PPI is probably the easiest to forecast. Such echoes generally travel with the mean wind between the 850 and 500 mb levels or with the 700 mb wind, with a slight tendency to deviate toward the right.[24] The direction and speed of these echoes may be readily determined from tracking on a PPI scope or by multiple exposures of a "Polaroid" camera or by means of storage cathode ray tubes. While this motion can be successfully extrapolated the value of such a forecast is limited due to the short lifetime of the cells. A number of radar studies have demonstrated that the median lifetime of a single shower cell is of the order of a half hour or less, although a few have been maintained for an hour or more. Hence, for an average cell speed of 23 knots the path length of an average shower would be only about 12 miles. Fortunately the short-lived showers are the least important with respect to the meteorological effects.

The motion of multiple-celled echoes or echo complexes, although somewhat more complicated because these generally deviate to the right of the upper winds, is rather constant in speed and direction. Hence extrapolation of the motion obtained from the radar is the best forecast technique. Because these echo complexes are relatively long-lived, of the order of an hour or longer, their paths can be forecast successfully and accurately. When one or more of these are observed on the radar upwind from the area of interest, their positions should be plotted at half-hourly intervals preferably using the forward edge of the echo which is generally sharply defined. The predicted arrival time of the echo (thunderstorm) should be adjusted periodically according to the latest average speed. The forecaster should also be on the alert for the possibility of the development of new cells downwind from existing ones which could upset a forecast.

5.2.2 Forecasting of Echo Line Motion

The motion of echo lines as shown by several studies[24, 25, 26] in various parts of the United States is persistent and rather conservative for any particular line (Fig.5-22). Hence the motion (speed and direction) as determined by tracking on radar is probably the best indicator of future movement. The short term motion may be erratic, hence when the line first appears on the radar it is advisable to estimate the motion by using the 700 mb wind component and to use the radar motion only after the line has been under observation for at least one hour. The following is suggested as a procedure to be used in forecasting the arrival of a line:

A. When the line is first observed and during the first hour

1. Obtain the best possible estimate of the current 700 mb wind field in the vicinity of the line. This may be obtained from the latest 700 mb chart which has been brought up-to-date by the latest winds aloft and extrapolation, or by tracking small echoes on the radar for about a half hour (these move very nearly with the 700 mb wind).

2. Compute the component of the estimated wind normal to the echo line, $u \cos \theta$, where u is the estimated 700 mb wind and θ is the angle between the 700 mb wind direction and the direction of the line motion (normal). (See Figure 5-23.)

3. Correct this estimate to allow for the propagation or development effect as follows:

700 mb normal wind component (knots)	0	10	20	30
Adjusted line speed estimate (knots)	10	18	22	30

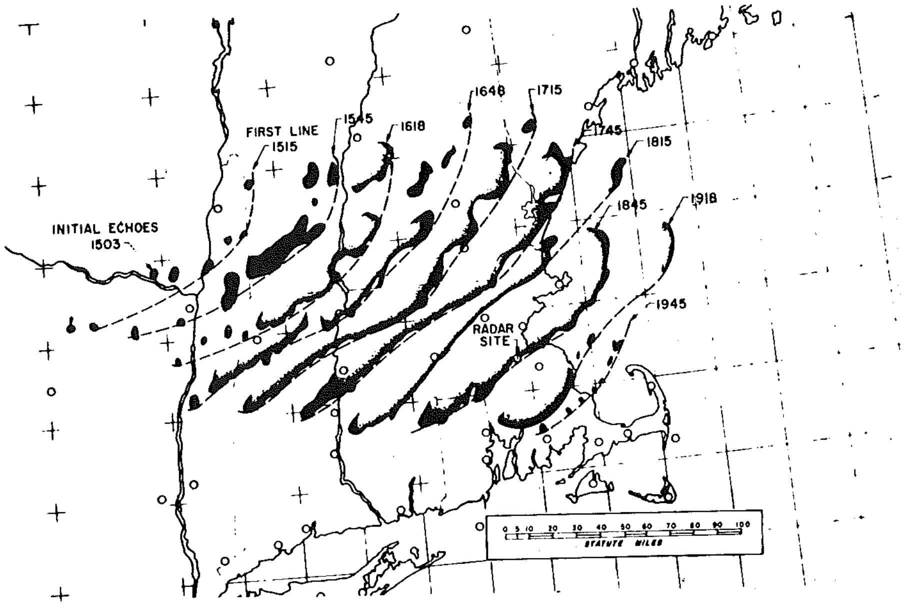


Figure 5-22. Tracing of the Forward Edge of a Squall Line at Approximately Half Hourly Intervals from First Appearance to Dissipation.[26] From AFCRL Blue Hill CPS-9 Radar.

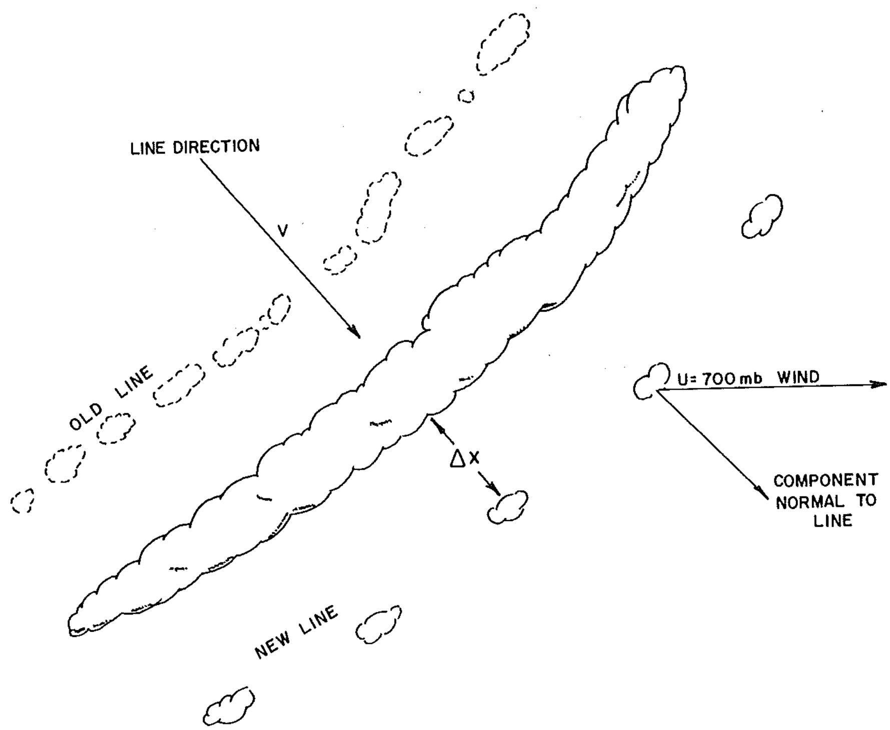


Figure 5-23. Concept of Squall Line Advancement Through a Combination of Cell Motion and Formation of New Cells Ahead of the Old Line. Line Speed $V = U \cos \theta + \frac{\Delta x}{\Delta t}$, where U = Cell (or 700 mb Wind) Velocity and θ the Angle Between Cell Direction and Line Direction. $\frac{\Delta x}{\Delta t}$ is a Propagation Term which Becomes Important for Slow-Moving Lines

4. Extrapolate the line toward the area of interest by this estimate.

B. After the line has been under radar observation for at least one hour:

1. Determine the speed of the smoothed forward edge of the line.

2. Use this speed to extrapolate the line.

3. Repeat at hourly intervals using the cumulative average line speed and not the latest hourly value to extrapolate the line.

Of the three methods of obtaining an estimate of the line speed, 700 mb wind, cell echo motion and radar line motion, the latter is probably the simplest and because of this it should be used after the line has been observed for one or two hours. The 700 mb wind and cell motion may be used initially and as a check on the radar line motion. Alternatively when dealing with squall lines especially in central or southern United States the 850 mb - 300 mb vector mean wind may be used instead of the 700 mb wind to estimate line motion.[13]

An approaching line which is not changing intensity will appear to lengthen rapidly following initial detection at or near maximum range, lengthen more slowly as it approaches the radar and then diminish in length as it recedes. Signs of a weakening line that is approaching are: decreasing length, lowering of the tops of the cells which make it up and lessening of the intensity of the cells.

Much of the important thunderstorm activity particularly when squall lines develop can be related to the development of weather systems on the mesoscale. The plotting and analysis of hourly surface sectional charts, including the composited radar information from those stations within the area of interest, will be highly useful for locating small-scale features and extrapolating their movement.

Super-imposing the contemporary radar echoes on such charts will not only reveal the close connection between important echoes and the mesosystems but also will enable the forecaster to use both the radar information and the synoptic analyses in a more intelligent manner.

Three examples of coordinated radar-synoptic analyses performed under operational conditions are shown in Figures 5-24 through 5-26. The first of these, (Fig. 5-24), at 1800 EDT on 14 May 1963 shows a mesoscale and radar analysis over New England. Radar echoes shown on the figure in solid black are from the AN/FPS-77 radar at Hanscom Field, Bedford, Massachusetts (star) while the hatched echoes are from the

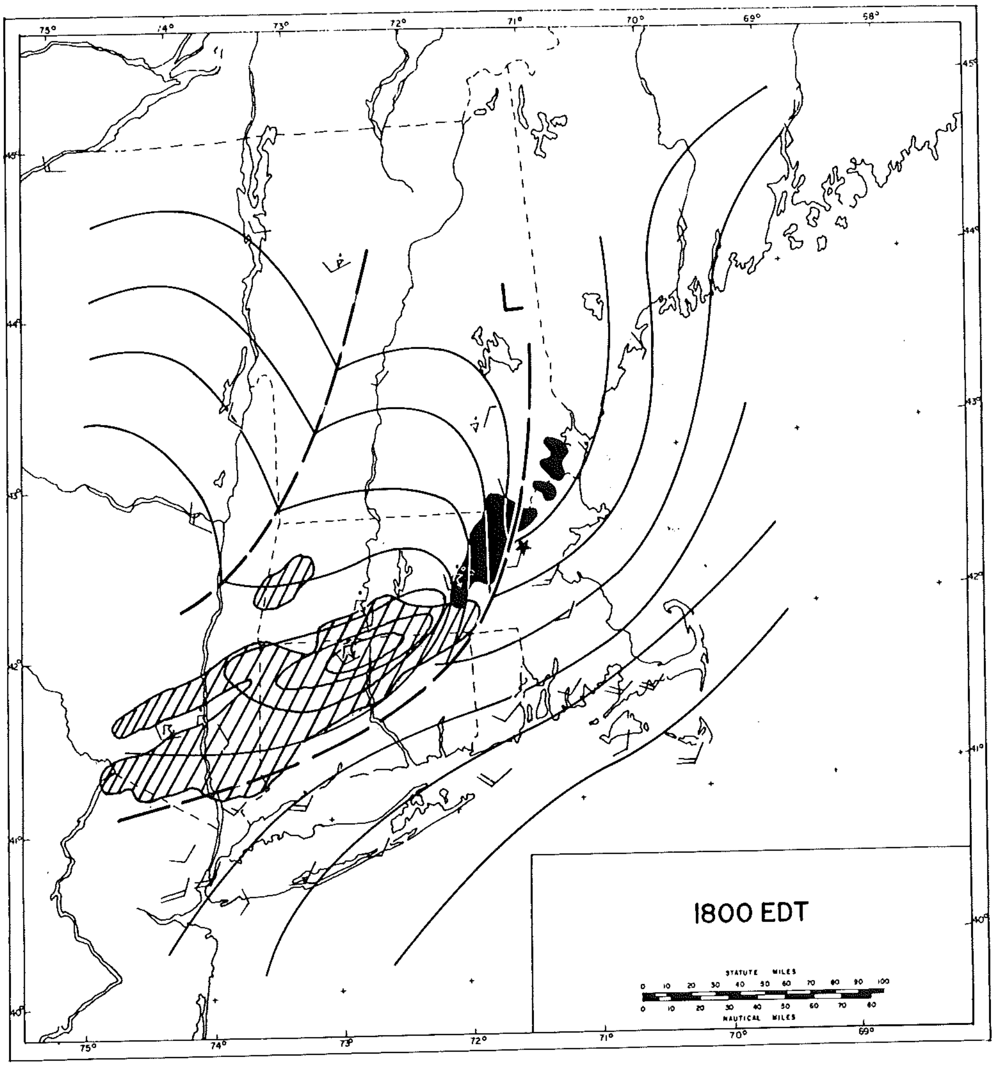


Figure 5-24. A Composite Radar and Mesoscale Analysis of a New England Squall Line, 14 May 1963. Solid Echo from AN/FPS-77, Hanscom Field, Hatched Echo from WSR-57 New York City. Isobars at 1 mb Intervals. Dashed Line in Advance of Echo Line Is the Wind Shift or First Gust Line from the Thunderstorm Outflow. Note Meso High Over Northern Connecticut.

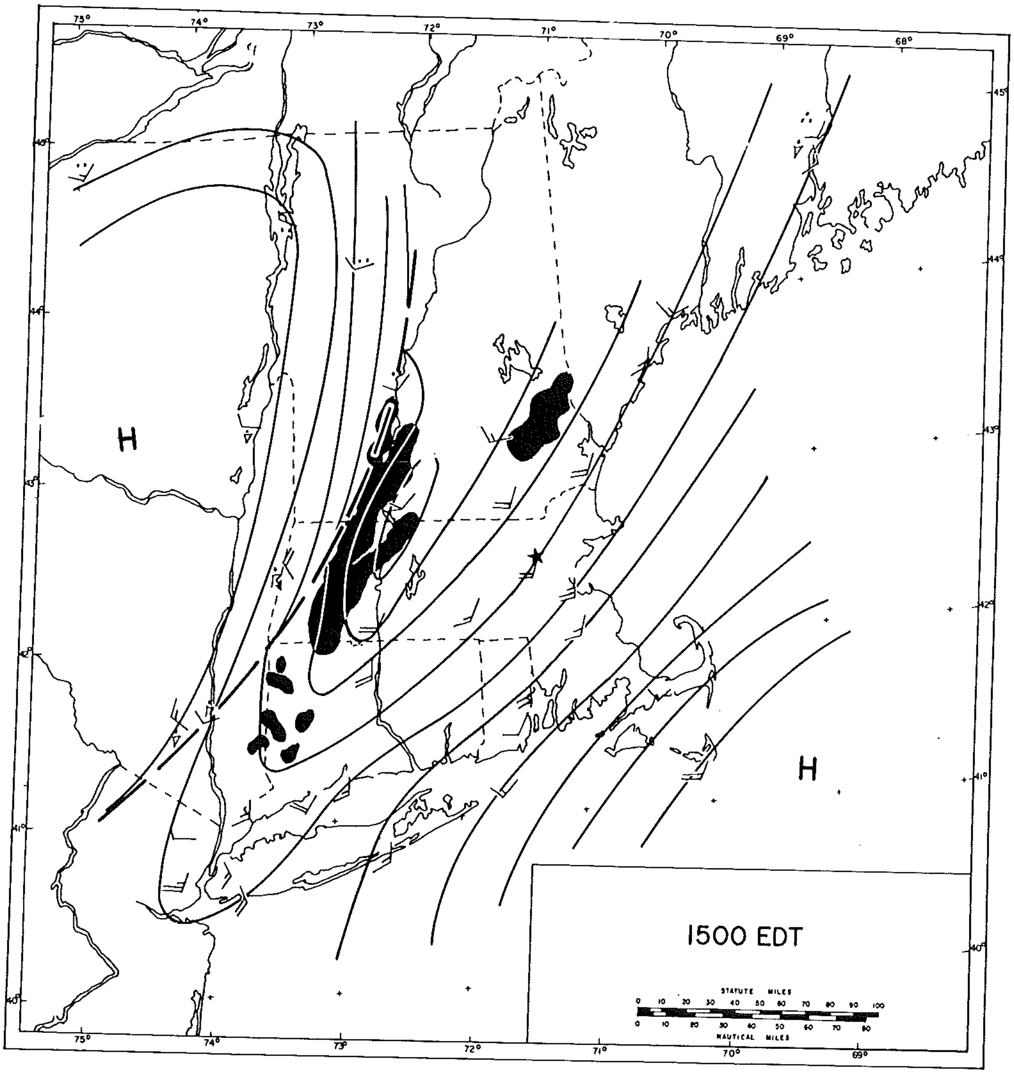


Figure 5-25. Radar and Mesoscale Analysis of a Severe New England Squall Line, 20 May 1963. Three Small Tornados Occurred in the Vicinity of the Meso Low in Proximity to the Echo "Finger." AN/FPS-77, AWS (Hanscom Field) Radar

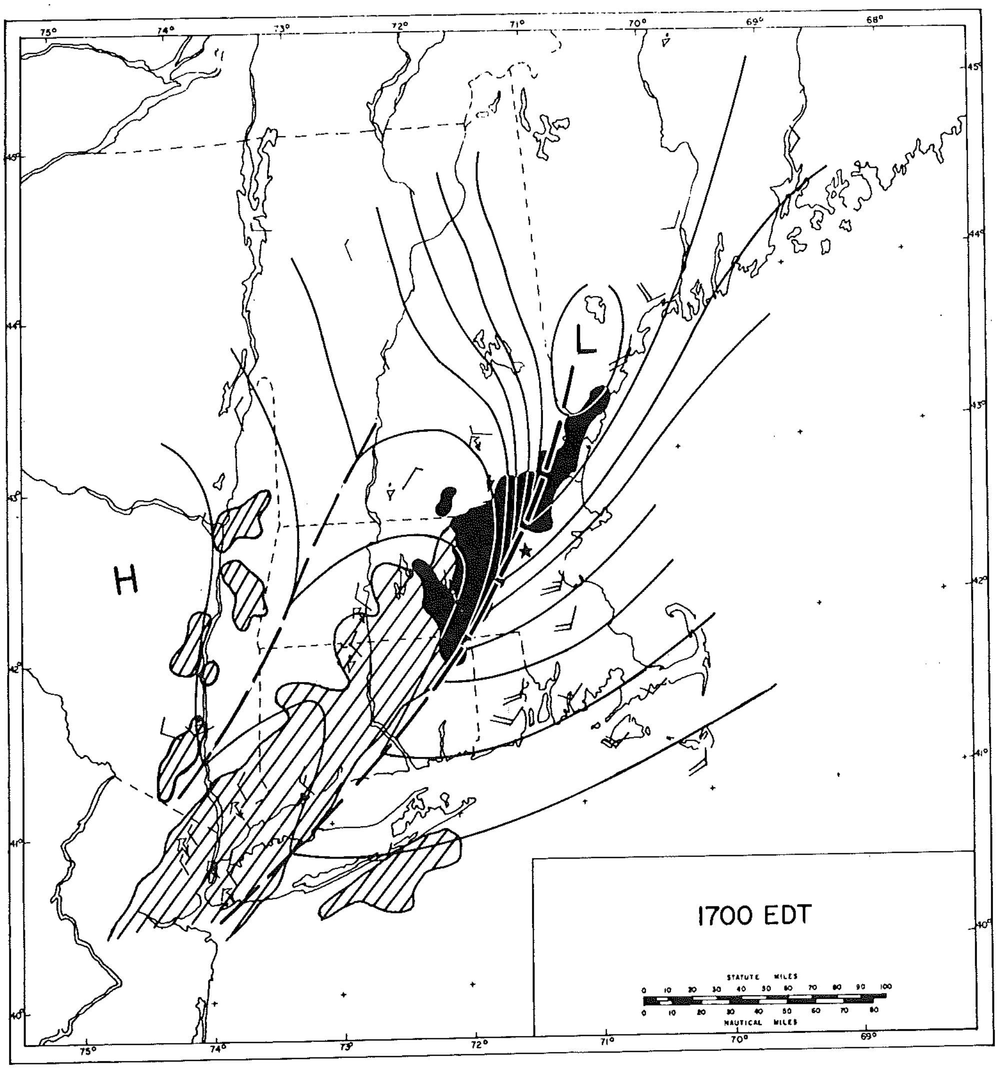


Figure 5-26. Composite Radar and Mesoscale Analysis 2 Hours After Figure 5-25. Solid Echo: AN/FPS-77, Hanscom Field; Hatched Echo: WSR-57, New York City. Note Development of Meso Ridge.

WSR-57 at New York City. This demonstrates how two radars can be used to complement their individual coverage. The coverage of the New York WSR-57 is considerably enhanced as a result of its superior site whereas the AN/FPS-77 is adversely affected by its relatively poor site. The mesoscale analysis associates the squall line echoes clearly with a trough and wind-shift line which corresponds with the first gust line or thunderstorm outflow. Note in this connection the well-developed meso-high centered over northern Connecticut. At this advanced stage, the cold outflow has outrun most of the echo and in New England this is indicative of a decaying squall line.

The second example (Fig. 5-25), is fairly typical of the more severe squall lines in this region, with a clearly defined meso-low in the Connecticut valley at 1500 EDT. The most severe weather, consisting of three small tornadoes, occurred during the next half hour in the vicinity of the projecting "finger" of echo in the lower portion of the meso-low.

The third example, (Fig. 5-26), shows the meso-low now in southwestern Maine with the gust-line or cold outflow beginning to outrun the echo. Again the complementing coverage of two radars is well demonstrated.

Because the lifetime of squall lines and precipitation lines in general is limited, the chance or probability that a particular line will arrive at a terminal will depend on its speed and its distance from the terminal. This problem will be taken up in Section 5.2.4.

5.2.3 Forecasting of Echo Field Motion

5.2.3.1 Edged Fields

During the colder seasons the oncoming precipitation echo field from an approaching storm will often display a rather sharp leading edge. The presence of this edge, which is partly due to the evaporation of the light precipitation as it falls into the dry air of the receding high, is a definite asset to the radar forecaster because it furnishes a convenient and effective means of tracking the advance of the echo field. Furthermore, the direction and speed of the edge has been shown to have a high degree of persistence, but unlike the line, the edge motion appears to be quite unrelated to the wind at any level. Hence it is very important that radar reports indicate this motion.

Because the edged echo field has such great persistence and long life, it lends itself readily to extrapolation methods in forecasting the onset of precipitation at a terminal. The suggested procedure for doing this is as follows:

1. As the echo edge appears on the PPI scope, generally about 100 miles from the radar, trace its outline on the scope face or an overlay map every half hour.

2. Measure the displacement perpendicular to the edge at hourly intervals and average each new measurement with the previous.

3. Extrapolate the motion on the basis of the average speed, and estimate arrival time of the precipitation. Avoid speed estimates on the basis of short period motion because the latter may depart considerably from the average speed and be misleading.

4. Check forecast hourly on the basis of the latest average speed of the edge.

5.2.3.2 Random Fields

Widespread cyclonic precipitation, more frequently than otherwise, results in radar echo areas or fields that have no unique characterization of shape because they possess neither sharp edges nor do they consist of lines. These random areas are an important class because they have a relative frequency of about twice that of lines and edged areas combined.

In general, the outline of the random area, including the forward portion, changes shape from hour to hour and remains poorly defined. This makes it difficult to characterize and quantize the motion of the area in order to be able to extrapolate it for forecast purposes.

Because such echo fields generally encompass more than the area within range of a single radar the true center or centroid of the echo cannot be determined and hence the motion of the centroid cannot be used to characterize the motion of the area of random echoes. Until such time that radar data processors and compositors permit an entire radar echo field to be presented at a forecast center, the following extrapolation technique will be found useful in forecasting the onset of precipitation at a terminal from random echo areas:

1. Determine the direction and speed of the small echo elements, if possible, otherwise obtain a value of the 700 mb wind representative of current conditions over the echo field.

2. Using either the echo element velocity or the 700 mb wind, extrapolate the edge of the nearest upwind echo from the terminal, within a 10° angle subtended from the terminal (5° either side of the wind or echo element direction).

3. Check forecast hourly on the basis of latest PPI information. Trial forecasts of the onset of precipitation from random areas using the above technique indicate good results for forecast periods up to three hours. For longer intervals, the precipitation tends to arrive at the terminal ahead of forecast due to the development of new precipitation in advance of the pre-existing field.

5.2.4 Probability of Onset of Precipitation at a Terminal

It is highly useful for operational purposes to estimate the probability of precipitation reaching a given terminal. Experiments with various types of radar echoes indicate: (1) the probability of the arrival of precipitation at a terminal is an inverse function of the distance of the echo from the terminal, i.e., the farther away it is the less likely it is to get there and (2) the probability varies considerably from one echo type to another.

Figure 5-27 shows the probability of precipitation arrival at a terminal for three modes of radar echo derived principally from data in the New England area. Estimated travel time to the terminal is used here to normalize the varying echo speeds. The figure shows that for the same estimated travel time, echoes from random fields have by far the greatest probability of reaching a terminal while line echoes have the least.

5.2.5 Likelihood of Precipitation-Related Hazardous Weather

5.2.5.1 Turbulence

A general appraisal of the probable presence or absence of turbulence may be made by an inspection of the PPI and RHI indicators. In general, the appearance of cellular or convective echo patterns, whether in the form of isolated cells or cellular echoes imbedded in a relatively smooth, stratiform echo area, is an indication of the presence of turbulence because the convective echo implies localized and relatively strong vertical motion. Even in a winter high latitude storm, there are areas in proximity to the center where the radar display indicates the presence of cellular echoes, which is in contrast to the smooth uniform echo characterizing the precipitation at a greater distance from the center. Within the cellular echo area, turbulence is frequently encountered, while smooth air is the rule in the uniform echo region. Again the presence of a well-defined bright band in reduced gain RHI presentations is another indication of relatively smooth air in widespread rain situations.

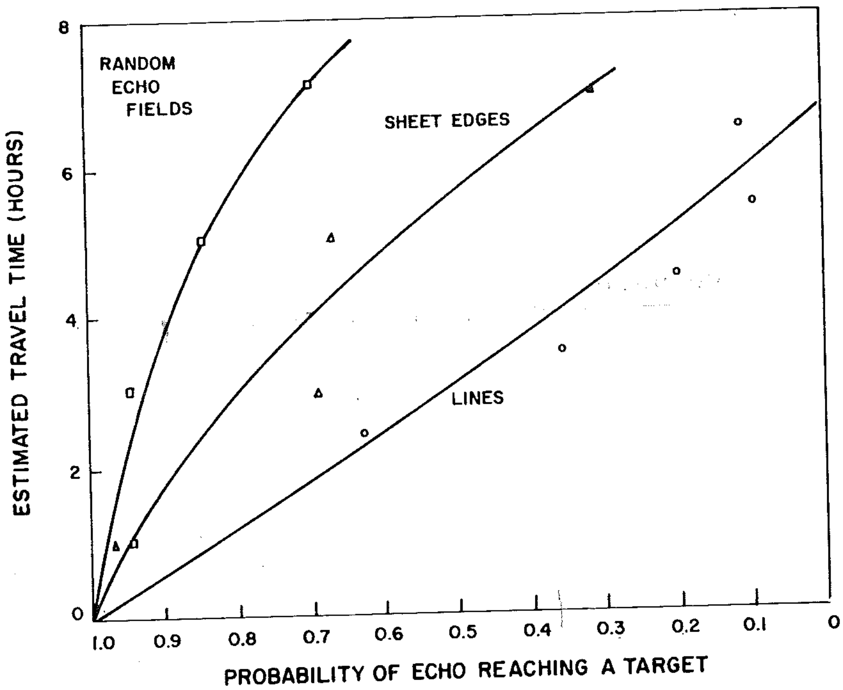


Figure 5-27. Empirically Derived Probabilities of Echo Reaching a Point Target as a Function of Estimated Travel Time to the Target. Curves are for Three Different Classes of Echo. Derived Principally from New England Data.

The National Severe Storms Laboratory of the Weather Bureau[27] has conducted an intensive study aimed at determining the radar echo criteria that can be used to signal the presence of turbulence in thunderstorms. While their data from radar coordinated thunderstorm penetrations show no direct correlation between radar echo intensity or gradient of reflectivity values and turbulence, the maximum reflectivity of the storm is the most reliable index of turbulence in thunderstorms. Moderate to severe turbulence may be encountered 10 to 15 miles from the core when the maximum reflectivity is $3.4 \times 10^4 mm^6/m^3$ or more. When the Z value exceeds 10^5 mm^6/m^3 encounters of severe to extreme turbulence can be expected. Furthermore moderate to severe turbulence is indicated if a rapid increase or decrease of reflectivity with time is observed in the reflectivity core, particularly for values of Z above $10^3 mm^6/m^3$. In over 90% of their cases, the most severe turbulence was encountered in either the center or the western portion of the thunderstorm complex as seen at the zero attenuation level.

It is important to bear in mind that some turbulence, even severe at times, is not associated with precipitation and hence is not indicated by radar. This is known under the general term of clear air turbulence (CAT) and may be found at any level in the atmosphere. Under storm conditions, the presence of low level turbulence due to orographic effects will not be indicated by radar.

5.2.5.2 Icing

Radar may be useful in estimating the probability of an icing encounter, the most likely area where icing will be found and the level or levels where it is likely to occur.

The type of echo pattern displayed on the PPI will give a good indication of the chance of encountering icing within the range of the radar. A uniform smooth echo, as shown in Figure 5-1, indicates gentle rising motion in the atmosphere with a minimum of liquid water present in the clouds, which indicates, at most, light icing with snow reaching the ground. In the case of rain at the ground, icing may be present in a limited region above the bright land.

If there is convective echo present on the PPI, this indicates the presence of cumuliform clouds which may be imbedded in the overall echo as in Figure 5-3. These contain considerable liquid water with large size cloud drops. The presence of such formations will be revealed on the RHI as high intensity echo cores at reduced gain. Above the melting level these represent shafts of heavily rimed snow crystals or graupel which grow in a cloud having a high liquid water content. Whenever these are present there will be limited regions of moderate to heavy icing within the buildups. Without the help of radar, these may not be evident to a pilot on instruments because of the intervening cloud.

Convective shower and thunderstorm situations where the buildups extend far above the melting level always imply moderate to severe icing conditions in the areas of growing cells.

The lower limit of icing will be determined by the melting level. The melting level may be determined from radiosonde data but may be more readily determined from the radar by scanning with the RHI at reduced gain. This will delineate the bright band, which is generally found about 1,000 feet below the 0°C isotherm. In convective cells, icing may be encountered at all levels where echoes are present on the radar above the melting level.

In general, the rate of icing decreases with temperature, simply because the lower the temperature the less water vapor is available for condensation into liquid water clouds. However, in the case of a vigorous updraft in a convective echo, air is lifted rapidly from lower, more moist levels so that it is possible for supercooled clouds that have a very high liquid water content to be produced in spite of the low temperatures. In flying through these, excessive rates of icing are sometimes encountered even at high altitudes. On the other hand in a region of smooth featureless echo, no significant icing can be expected in the upper colder portions of the echo.

5.2.5.3 Gusty Surface Winds

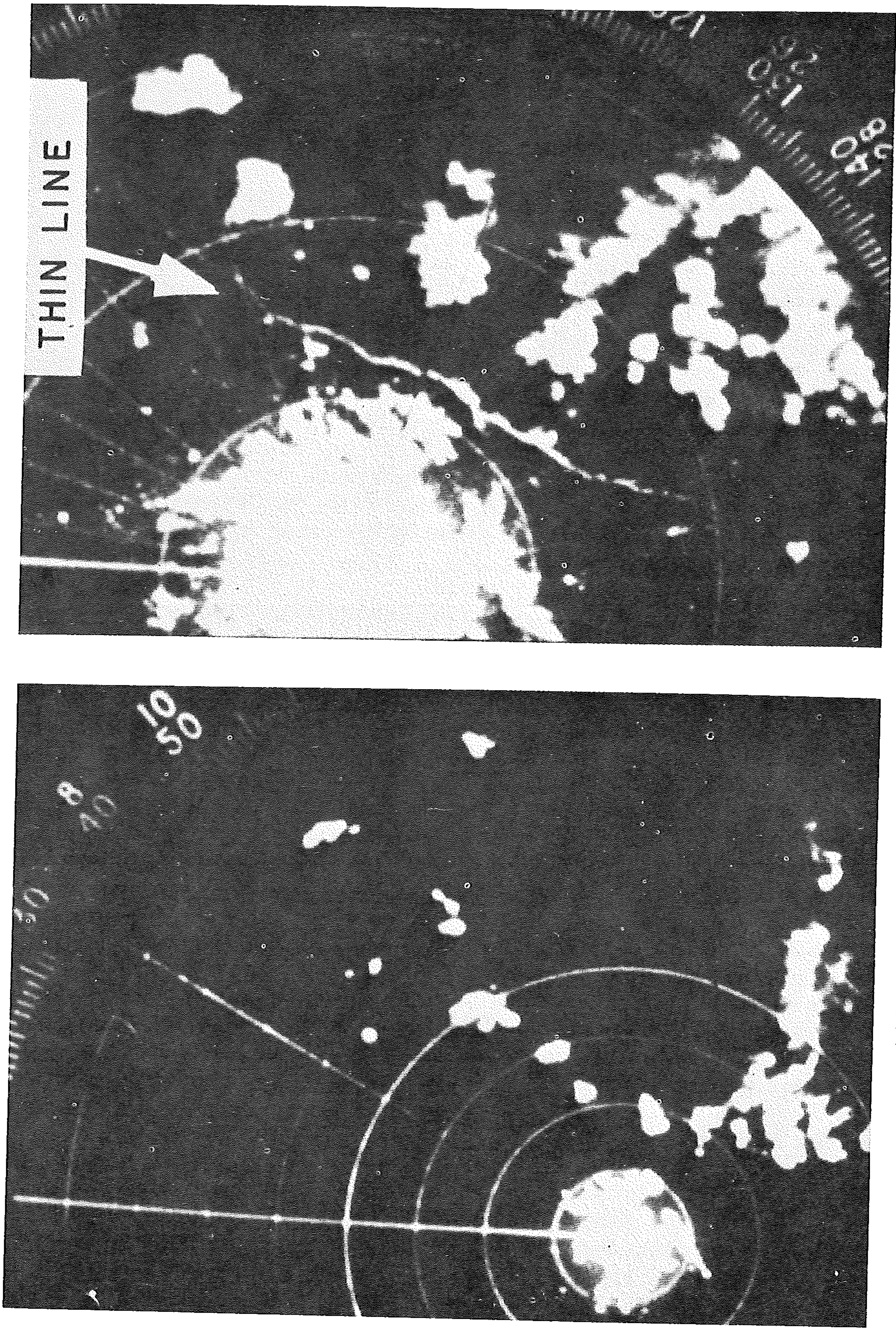
Gusty surface winds may occur under a number of meteorological circumstances. Principally, these fall into two main categories: intense cyclonic storms in which the winds increase over a time interval and, therefore, do not pose a serious forecast problem; and, sudden squall winds in which the winds intensify suddenly from low velocities to high gusty values and whose timing is of great importance for landings and takeoffs. The latter may also be of importance in the protection of life and property about a terminal. It is against the latter category that radar can offer the best advance warning.

Virtually all mature thunderstorms have gusty surface winds associated with them. Therefore, any convective echo or echo complex on the radar which is suspected of being a thunderstorm by virtue of the intensity of the echo, or its height, or both should be assumed to be capable of producing dangerous gusty surface winds as it approaches or passes within a few miles of the terminal. The more intense and larger the thunderstorm complex, the stronger may be the wind and the larger the area affected. The squall wind, which is the outflowing cold air from the thunderstorm, usually arrives a short time ahead of the precipitation echo and is principally effective on the forward side of the thunderstorm, i.e., on the side toward which it is moving.

Occasionally the forward edge of the outflowing cold air or the gust front, as it is sometimes called, is marked by a thin curving line of echo, Figure 5-28. In such cases this "thin line" will serve to mark the advance of the gustiness and track its progress. But the "thin line" is not a reliable indicator; it is frequently absent and its absence does not denote the lack of dangerously gusty winds.

5.2.6 Pilot Briefing

The radar briefing is of great help to the pilot because it provides him with a picture of the general nature of the situation which he may find useful in the event of unexpected developments. Squall lines and isolated thunderstorms are now much less likely to escape detection than



1432 C

1422 C

Figure 5-28. CPS-9 PPI Showing Development of Thin Line Associated with Gust Front. College Station Texas, 25 sm Range Marks.

before, particularly within the contiguous United States of the Rocky Mountans. Many aircraft are equipped with radar which pilots are able to use effectively for storm avoidance but surface radar can usually provide a somewhat more comprehensive picture than the airborne version. Hence, the surface radar is useful during briefing, in showing the pilot what he is apt to observe later with his own equipment.

It is not feasible for a network radar station to give specific vectoring information to pilots. However, general information on preferential routing for flight planning purposes can often be furnished pilots (in-flight or pre-flight) and flight controllers.

5.2.7 Storm Bulletins Based on Radar Information

Keeping the public well informed on prospective and current weather developments contributes to alertness and readiness to act in event of a weather emergency. Radar provides information for frequent up-to-the-minute releases of weather within or approaching the local area. The practice followed by radar stations is to release information in the form of radar weather summary, severe weather statements, or warnings (as appropriate) each hour, and more frequently during rapidly changing conditions.

Statements containing radar data should be in consonance with the instructions contained in Chapter III-B-18, Severe Local Storm Warning Service. If the message is to be entered on an ESSA Weather Wire, it should be in agreement with instructions governing entry of data on those circuits. Basically, a radar weather summary is a general summary of the location, movement and intensity of detected echoes, along with an estimate of the character of the surface weather associated with these echoes. As the reported weather or the radar indications increase in intensity severe weather statements or warnings will be issued. Reports of damaging winds, hail or heavy rains should be called "Severe Weather Statements." Such a designation carries more of a sense of urgency than does a radar summary heading. The severe weather should be associated with the radar echoes. When a severe thunderstorm or tornado is indicated, the message should be labeled a "Severe Thunderstorm Warning" or a "Tornado Warning" as appropriate. Warning information should be highlighted, not "lost" in a statement or radar summary. Chapter III-B-18 gives a suggested format for warnings.

5.2.7.1 Format for a Weather Radar Summary

The recommended format for a weather radar summary is as follows:

Time of release (hour, minute, am or pm, month, day, year); Weather Bureau; city and state (originator of message). Local standard time, or local daylight time (as appropriate) will be used.

Present location of weather activity with reference to locations well-known to the public.

Movement of weather, giving direction and speed.

Areas likely to be affected, including time of beginning, or ending.

Weather expected, (for example, squally weather, showers, thunderstorms, damaging wind, etc.).

Examples of a weather radar summary, a severe weather statement, a severe thunderstorm warning and a tornado warning:

CHICAGO WEATHER RADAR SUMMARY
FRIDAY APRIL 21 1967
TIME...234 PM CST

AT 215 PM CST THE CHICAGO WEATHER RADAR SHOWED SCATTERED MODERATE RAIN SHOWERS AND THUNDERSTORMS OVER EASTERN IOWA AND ILLINOIS FROM MOLINE TO 40 MILES SOUTH OF TERRE HAUTE INDIANA. THERE WAS A LINE OF SCATTERED THUNDERSTORMS FROM 60 MILES NORTH OF MOLINE TO 40 SOUTH OF TERRE HAUTE INDIANA. THE LINE WAS MOVING NORTHEAST AT 30 MILES AN HOUR. THERE WAS A LINE OF THUNDERSTORMS FROM 40 MILES SOUTHWEST OF MADISON WISCONSIN TO 20 MILES SOUTH OF OTTUMA IOWA. THIS LINE WAS MOVING EAST AT 10 MILES AN HOUR.

END

TORNADO STATEMENT
ESSA WEATHER BUREAU CHICAGO
FRIDAY APRIL 21 1967
TIME...5.15 PM CST...

A TORNADO WAS REPORTED IN THE VICINITY OF WEST CHICAGO BY ILLINOIS STATE POLICE AT 5.10 PM MOVING EAST TOWARD WHEATON.

END

SEVERE THUNDERSTORM WARNING BULLETIN

A SEVERE THUNDERSTORM WARNING IS IN EFFECT UNTIL 5.00 PM FOR PERSONS IN WINNEBAGO BOONE DEKALB AND OGLE COUNTIES IN ILLINOIS. A LINE OF THUNDERSTORMS WAS INDICATED BY RADAR 50 MILES SOUTHWEST OF ROCKFORD ILLINOIS AT 254 PM THE SEVERE THUNDERSTORMS ARE MOVING TOWARD THE EAST NORTHEAST.

ESSA WEATHER BUREAU ROCKFORD ILLINOIS

TORNADO WARNING BULLETIN
EMERGENCY ACTION NOTIFICATION SIGNAL REQUESTED

A TORNADO WARNING IS IN EFFECT UNTIL 6.30 PM FOR PERSONS IN ALL OF COOK...DUPAGE...AND KANE COUNTIES.

A TORNADO WAS INDICATED BY RADAR 7 MILES NORTH OF ELGIN AT 5 PM. THIS TORNADO IS MOVING TOWARD THE EAST.

ANOTHER TORNADO WAS REPORTED BY THE PUBLIC IN NORTH BARRINGTON ILLINOIS. THIS TORNADO IS MOVING TOWARD THE EAST.

IF A TORNADO IS SIGHTED...BE PREPARED TO MOVE TO A PLACE OF SAFETY.

ISSUED 5 PM CST FRIDAY APRIL 21 1967
ESSA WEATHER BUREAU CHICAGO.

5.2.7.2 Source for Official Procedures and Other Examples

The Weather Bureau Manual, Volume III, Service Operations, contains more detailed instructions for preparing and issuing various types of storm bulletins. These bulletins are often based upon visual reports by the public, special surface synoptic observations, PIREPS, etc., as well as radar observations. Chapter B-50 covers the Hurricane Warning Service.

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Chapter 6

SELECTIVE QUANTITATIVE RADAR TECHNIQUES

6.1 PRECIPITATION INTENSITY DETERMINATION

Radar provides a means of obtaining approximate rainfall intensities over a relatively large area ranging up to about 10,000 square miles. Although the accuracy, when compared with a given rain gauge, may not be high, when considered on an area basis, radar measurements may give a better estimate of actual rainfall than any practical number of rain gauges distributed over the same area.

6.1.1 Radar Calibration

A properly calibrated radar is essential if it is to be used to determine rainfall intensity. In principle if the radar specifications are known the rain intensity may be estimated from the radar equation by using a given Z-R relation; however, in practice the radar characteristics are subject to day-to-day change particularly with regard to the minimum detectable signal, the different gain settings and the recording of a signal of known intensity. Hence, ideally calibration should be made on the same day as the quantitative measurements.

Calibration is frequently made by feeding signals of known intensity into the antenna, and determining the values of the received signal at different gain settings as indicated on a recorder. The gain setting at which a signal just disappears is also determined. This latter calibration, although less accurate, is particularly useful in interpreting precipitation intensity. For a more accurate calibration, the received echo from a target of known reflectivity, such as an aluminum sphere, at a range of a few miles is measured at different gain settings.

6.1.2 Z-R Relations

The relation between the reflectivity factor Z in mm^6/m^3 and then rain intensity R in mm/hr depends on the drop size distribution. The relations $Z = 200\ R^{1.6}$ for steady rain and $Z = 486\ R^{1.37}$ for thunderstorm rain are based on average values from many rainstorms.[1] Individual rainstorms may deviate considerably, so that a rain intensity derived from a given value of Z for any one storm may deviate by as much as a factor of 2 from that derived from the formula. The standard error of estimate is about 40%.* Although some attempts have been made to match

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* The standard error of 40% signifies that 68% of the cases are within that limit.

Z-R relations to different types of rain and to the synoptic situation, results have been inconclusive so that the standard Z-R relations are as good as any. An exception is the case of orographic rain in Hawaii where, because of the predominantly small drop size, the relation $Z = 31R^{1.71}$ was found.

The Z-R relation for snow varies according to the type of snow. A relation $Z = 500\ R^{1.6}$ is considered appropriate for snow consisting of single crystals. For aggregate snowflakes $Z = 2000R^{2.0}$ is reasonable. A good average relation for all types of snow is $Z = 1000R^{1.6}$.

6.1.3 Iso-Echo Contours

Photographs of the PPI at different IF gain settings produce equivalent iso-echo contours which may be interpreted as patterns of precipitation intensity if the range effect is considered. If range normalization is used, the contours from calibrated IF gain settings can be converted directly into precipitation intensities. In some techniques the gain settings are automatically changed after every sweep. In the case of two gain settings it is possible to produce a single photograph with the echoes within the inner contour darkened so as to show graphically the precipitation intensity structure. For multiple gain settings various shades of grey have been used.

6.1.4. Range Effects and Attenuation

Normalized echo intensities at different ranges may be interpreted in terms of precipitation intensity provided that the vertical structure of the reflectivity within the beam does not change and provided also that attenuation may be neglected.

In the case of steady rain the reflectivity at different ranges may be interpreted in terms of precipitation intensity as long as the beam does not penetrate through the bright band. The maximum range to which quantitative measurements may safely be made depends on the beam width, the height of the bright band, and the angle of elevation of the antenna. A bright band at 10,000 feet and a beam width of 2° at an elevation angle of 1° limits quantitative measurements to within about 60 n. mi.; for a 1° beam at an elevation angle of 1/2° the limit is about 80 n. mi. In the case of showers, conditions are quite variable but on the average quantitative measurements to somewhat greater ranges than in steady rain are possible.

Because of attenuation, quantitative measurements of rainfall rates greater than about 1 inch/hr should be made only with radars having wavelengths near 10 cm. At lesser rates, radars operating at wavelengths near 5 cm may be used, and radars operating near 3 cm may be expected to successfully measure rates up to about 1/2 inch/hr. Correction for attenuation is not feasible under ordinary operating conditions.

6.2 ACCUMULATED PRECIPITATION DETERMINATION

In hydrological applications it is frequently desirable to estimate the total rainfall over a relatively large area, such as a watershed. Radar may be ideally suited for such a purpose. Both photographic and electronic techniques are under development which will facilitate this procedure.

Methods in current use, however, are still largely subjective. One proposed technique, [2] makes use of multiple exposures of the PPI scope on "Polaroid" transparency film taken at 5 to 10 minute intervals over a period of one to two hours. The processed transparencies are then projected onto a map of the area and persistent echo regions are outlined. Then, by means of rainfall rate estimates made during the integration period and actual rainfall reports, it is possible to arrive at some estimate of the quantitative rainfall pattern. This is generally done only for persistent echoes in potential flood situations.

Another technique is to outline iso-echo contours on the PPI scope hourly and transfer on a ten mile grid overlay map the appropriate range corrected equivalent rainfall rate. After 6 hours an isohyetal map is drawn from the totaled hourly values.

These are obviously only interim procedures to be eventually supplemented by some form of automated integrator-processor. A version of this processor, which is under development, is discussed in Chapter 9.

For a more complete discussion, see Chapter 11, "Radar Hydrology."

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Chapter 7

COMPARISON OF CHARACTERISTICS AND DIFFERENCES OF THE AN/FPS-77, WSR-57*, CPS-9 AND THE AN/TPQ-11

7.1 RADAR CHARACTERISTICS

The characteristics of a given radar under operating conditions may vary appreciably from those specified by the manufacturer. It is not unusual, therefore, for different references to give different values for some of these characteristics, particularly antenna gain and minimum detectable signal. Table 7-1 gives the characteristics for four modern radars typical of K, X, C and S bands. Most of the listed values are standard but minimum detectable signal and antenna gain are subject to some uncertainties under operating conditions. Also included in the table are values of the radar constant R_c from Equation (1) of Chapter 3 from which may be determined the minimum detectable Z at a given range. These values were calculated for long pulse and the theoretical antenna gain with 65% efficiency was used for the CPS-9 calculation.

The theoretical gain utilizes Equation (2) with the effective area 65% of the actual area. Measurements of the characteristics of the CPS-9 were made on a prototype model at M.I.T. The measured gain of 41.6 db gives an effective antenna area of only 15%. Because this value is far below the 65% found in other radars, and because the production models may be improved in this respect, the 65% effective antenna area was used.

The minimum detectable signal of the WSR-57 is listed as -109 dbm or 1.3×10^{-14} watts. However, in order to insure consistency between the various WSR-57 sets, these radars are calibrated to give a common reference level of -103 dbm or 5×10^{-14} watts. Therefore, the latter value was used for determining the radar constant.[1]

If P_m is the minimum detectable signal and P_r is the received signal, then $10 \log P_r/P_m$ represents the gain reduction in db required to blank out an echo. This gain reduction is also equal to $10 \log Z/Z_m$ where Z_m is equal to $P_m r^2/R_c$. More generally, including attenuation A in db the gain reduction GR is given by

$$GR = 10 \log Z - 10 \log Z_m - A$$

Figures 7-1 through 7-3 show the gain reduction necessary to blank out echoes with different values of Z at different ranges for the CPS-9, the AN/FPS-77 and the WSR-57, respectively. These charts include atmospheric and cloud attenuation (Table 3-2) but they do not include rain attenuation. The right hand scale shows equivalent rainfall intensity (in/hr) as

*The FPS-41 is essentially the same as the WSR-57.

Table 7-1

COMPARISON OF WEATHER RADAR CHARACTERISTICS

Parameter	CPS-9	WSR-57	AN/FPS-77	AN/TPQ-11
Band	X	S	C	K_A
Wavelength (cm)	3.2	10.3	5.3	0.86
Frequency (mcs)	9317	2700-2900	5450-5650	34500-35200
Peak power (kw)	250	500	300	140
PRF (pps)	931 and 186	658 and 164	324	1000
Pulse length (μs)	0.5 and 5	0.5 and 4	2	0.5
Beam width	1°	2°	1.6°	0.25°
Beam type	Conical	Conical	Conical	Conical
Range	350 n. mi.	250 n. mi.	200 n. mi.	60,000 ft
Ranging accuracy	±.1 mile	±0.5%	±.5% at Max Range	±1%
S min (w)	4.0×10^{-14}	5.0×10^{-14} (calib.) 1.3×10^{-14} (capable)	2.0×10^{-14}	1.3×10^{-13}
Receiver band width (mc)	2.5 and 0.25	0.3	0.6	2.5
Noise figure (db)	16	8 (approx)	9.5	16 (approx)
Antenna diameter (ft)	7.75	12	8	7 (2 each)
Reflector (type)	Paraboloid	Paraboloid	Paraboloid	Paraboloid
Antenna gain (Theoretical)	46 db	38.6 db	41.2 db	56 db
(Measured)	41.6 db	38.6 db	41 db	56 db
Radar constant (R_c)	2.3×10^{-10}	$.5 \times 10^{-10}$	1×10^{-10}	1×10^{-7} (for cloud drops)
Scan speed (auto-rpm)	5	4	5	N/A
Presentation	2 PPI, RHI, A/R	PPI, RHI, A/R	PPI, RHI, A/R	A, Recorder
Scope size (inches)	7, 7, 5	12, 7, 7	10, 10, 5	5, Fax-tape
STC (range normalization)	Yes	Yes	Yes	Yes
Iso-echo	No	Yes	Yes	Yes
Weight (less tower)(tons)	2	2.5	2	1.5
Cost (approx)	$175,000	$130,000	$40,000	$27,500

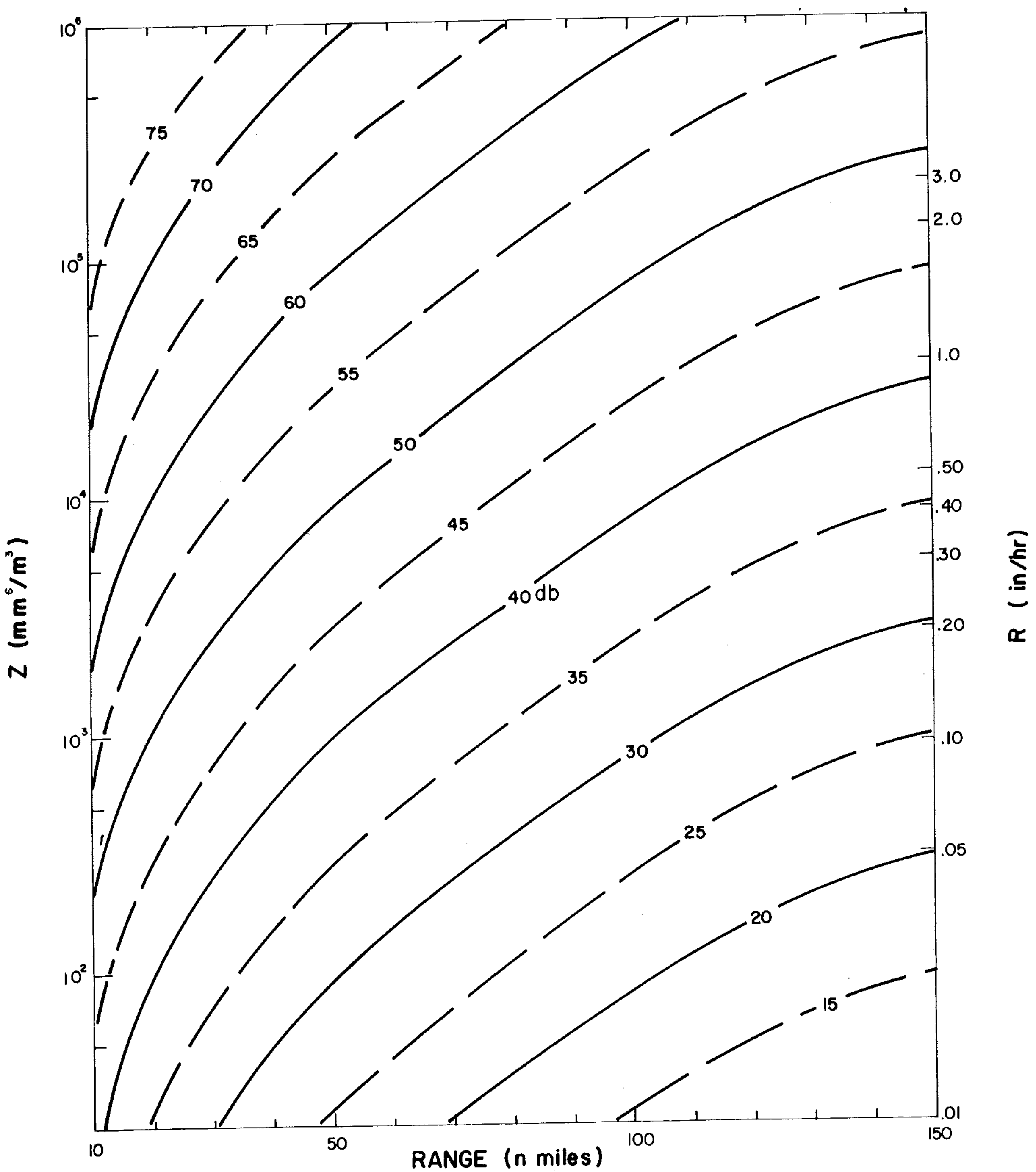

Figure 7-1. CPS-9 Gain Reduction Nomogram for Estimating Z at Different Ranges

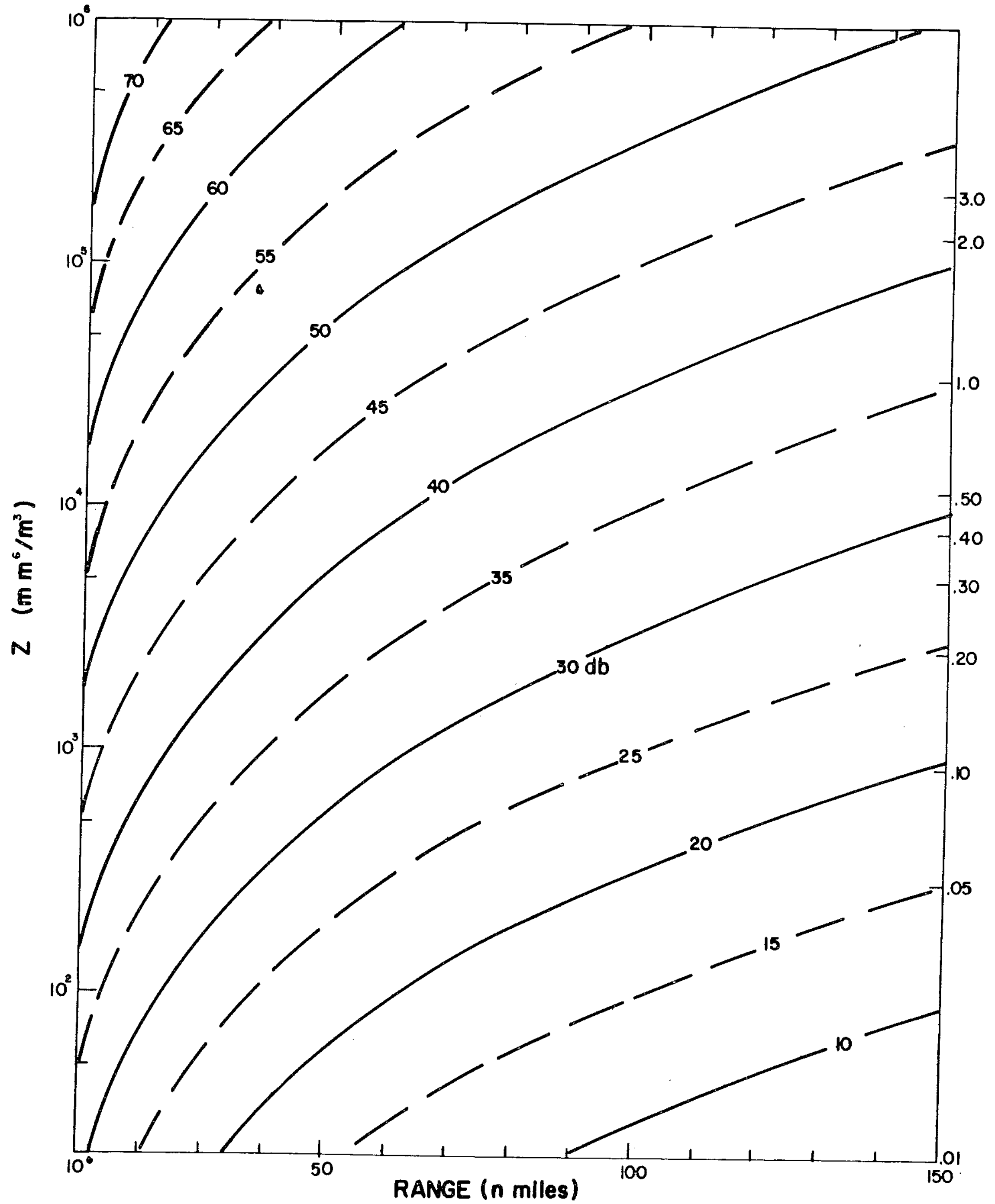

Figure 7-2. AN/FPS-77 Gain Reduction Nomogram for Estimating Z at Different Ranges

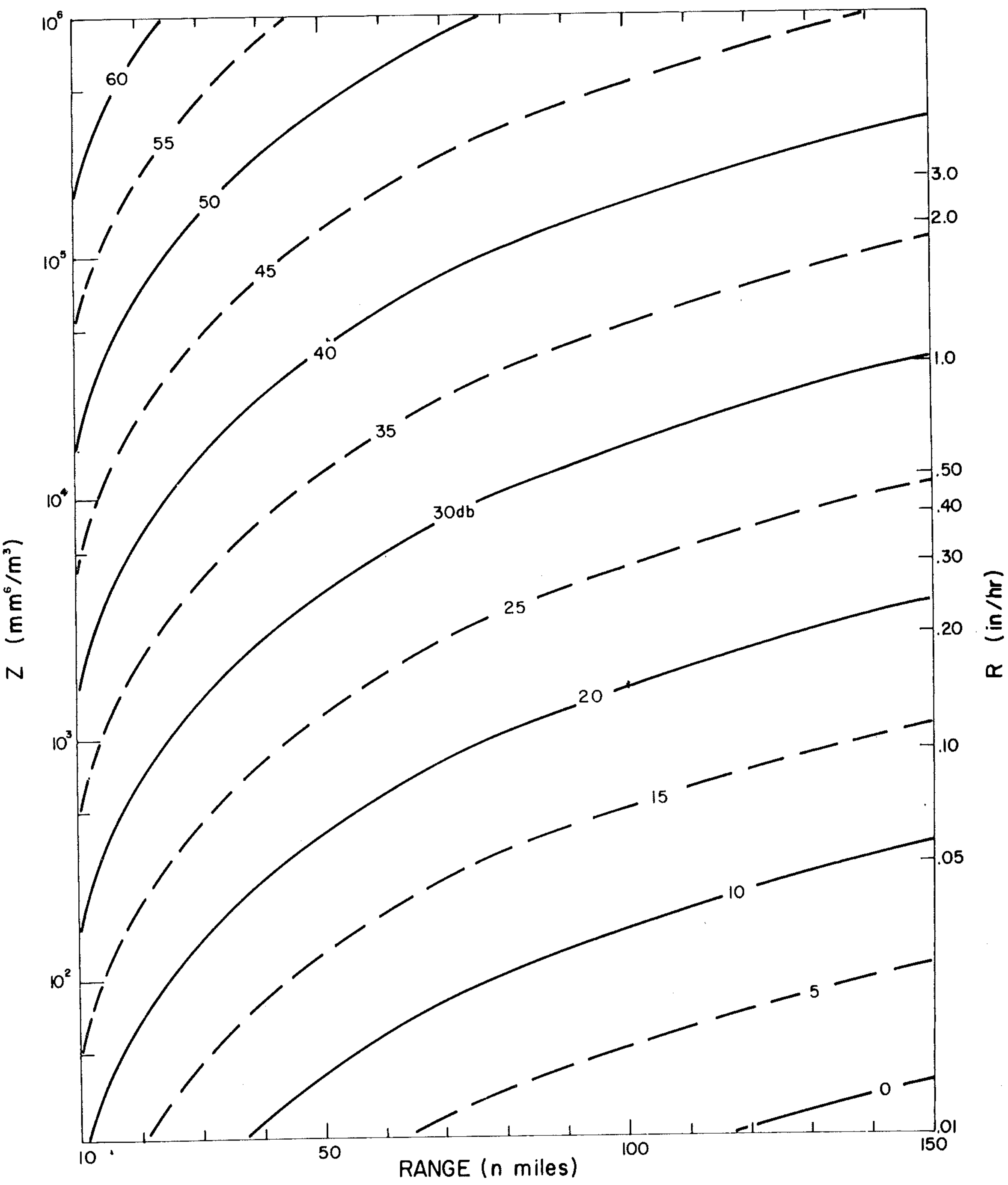

Figure 7-3. WSR-57 Gain Reduction Nomogram for Estimating Z at Different Ranges

determined from the relation $Z = 200R^{1.6}$. The charts do not take into consideration the variation of Z with altitude. Beyond ranges of about 70 miles the radar beam penetrates to greater heights in the atmosphere where the echo is considerably weaker. Hence a value of Z or rain intensity for a storm beyond about 70 miles, as determined from any of these charts, may be a gross underestimate of the actual value at lower levels in the storm.

For the same Z value at 100 miles and without intervening rain attenuation, the CPS-9 is about 13 db more sensitive than the WSR-57 and about 7 db more sensitive than the AN/FPS-77. However, rain attenuation, which seriously affects 3 cm radiation, changes these relative sensitivities. Thus attenuation over a 100 mile path by rain intensity of .15 in/hr, would render the AN/FPS-77 and the WSR-57 more sensitive than the CPS-9 for detecting precipitation beyond these distances.

Comparing the AN/FPS-77 and WSR-57 a rain of 0.6 in/hr over a 50-mile path or about 0.3 in/hr over a 100-mile path would make the WSR-57 more sensitive than the AN/FPS-77.

7.2 PERFORMANCE IN MODEL STORMS

For the actual performance in storm detection the radar site is of prime importance. An optimum site is one which allows unrestricted use of a low antenna elevation angle, 0 to 1/2 degrees. The range of detection is limited by the fact that at increasing range the radar beam extends higher into the atmosphere where portions of the beam sample the weaker echoes aloft or extend above the precipitation. It should be noted, however, that a site favorable for long range detection, such as a hilltop, generally has an increased area of ground clutter in the vicinity of the radar. While this does interfere with radar detection of weather echoes within the ground clutter area, the interference may be eliminated by raising the antenna elevation angle.

Figures 7-4 through 7-6 evaluate the theoretical performance of the three radars by assuming that the antenna is directed at an elevation angle of 1/2 degree. This angle is not necessarily optimum for obtaining maximum echo intensity at all ranges but it is a reasonably good angle for normal PPI operation. At this angle about 8% of the energy of the 1.6 degree beam of the AN/FPS-77 and 15% of the energy of the 2.2 degree beam of the WSR-57 intercepts the surface below the horizon.

The performances are evaluated for a model reflectivity profile in stratiform precipitation with 0°C at 8,000 and 14,000 feet, or for a low and a high melting level. The bright band with reflectivity four times that of the rain is assumed to extend 1,000 feet below the 0°C level, i.e., at 7,000 and 13,000 feet. Above the 0°C level the reflectivity drops off exponentially, and the echo top is 10,000 feet above the 0°C level, i.e., at 18,000 and 24,000 feet.

Figures 7-4 through 7-6 also give the gain reduction criteria for distinguishing between light rain (R-), moderate rain (R) and heavy rain (R+), where 0.1 in/hr is the upper limit for light rain, and 0.3 in/hr the upper limit for moderate rain. The heavy rain category is omitted for the low melting level case because it is unlikely to occur under that condition. The equation $Z = 200R^{1.6}$ is used to compute the reflectivities, and atmospheric attenuation (Table 3-2) is taken into consideration in constructing the curves. Separate curves are constructed for the case of no rain attenuation (labeled "no att.") and for the cases of attenuation through continuous rain of 0.1 in/hr (R att) and 0.3 in/hr (R + att.) for the CPS-9. All curves are normalized to 100 miles.

For the WSR-57 (Fig. 7-4) the gain reduction criterion separating light and moderate rain is about 20 db out to about 60 miles for the low melting level. The curve separating moderate and heavy rain is 7.5 db greater than the light to moderate curve. Beyond about 70 miles for the low melting level and 75 miles for the high melting level, the curves dip sharply to lower gain reductions as the weaker echoes at higher levels are sampled. Rain attenuation is not considered in these diagrams because at 10 cm it may be neglected. The maximum range for the detection of 0.1 in/hr is about 130 miles for the low melting level and close to 150 miles for the high melting level.

Figure 7-5 gives the curves for the CPS-9. Considering the lower set of curves (low melting level) the gain reduction criterion distinguishing between light and moderate rain for no rain attenuation is 34 to 35 db out to about 70 miles, after which it drops off sharply. With attenuation due to intervening rain of 0.1 in/hr, the curve is lower by 6 db at 50 miles and by 12 db at 100 miles. For the upper set of curves (high melting level), the gain reduction for moderate rain without attenuation (curve A) is 30 to 36 db out to 100 miles, and the heavy rain criterion curve (curve B) is 7.5 db greater. Attenuation due to intervening moderate rain (0.1 in/hr) lowers curve A by about 12 db per 100 miles, while attenuation by heavy rain (0.3 in/hr) lowers curve B by 21.5 db in the first 50 miles. The diagram demonstrates that considerable ambiguity may arise in measurements at 3 cm. For example, a measured gain reduction of 28 db at 40 miles could either be due to the detection of moderate rain through light to moderate rain or to the detection of heavy rain through moderate rain. This points to the difficulty of making meaningful quantitative measurements at 3 cm when attenuation becomes a significant factor.

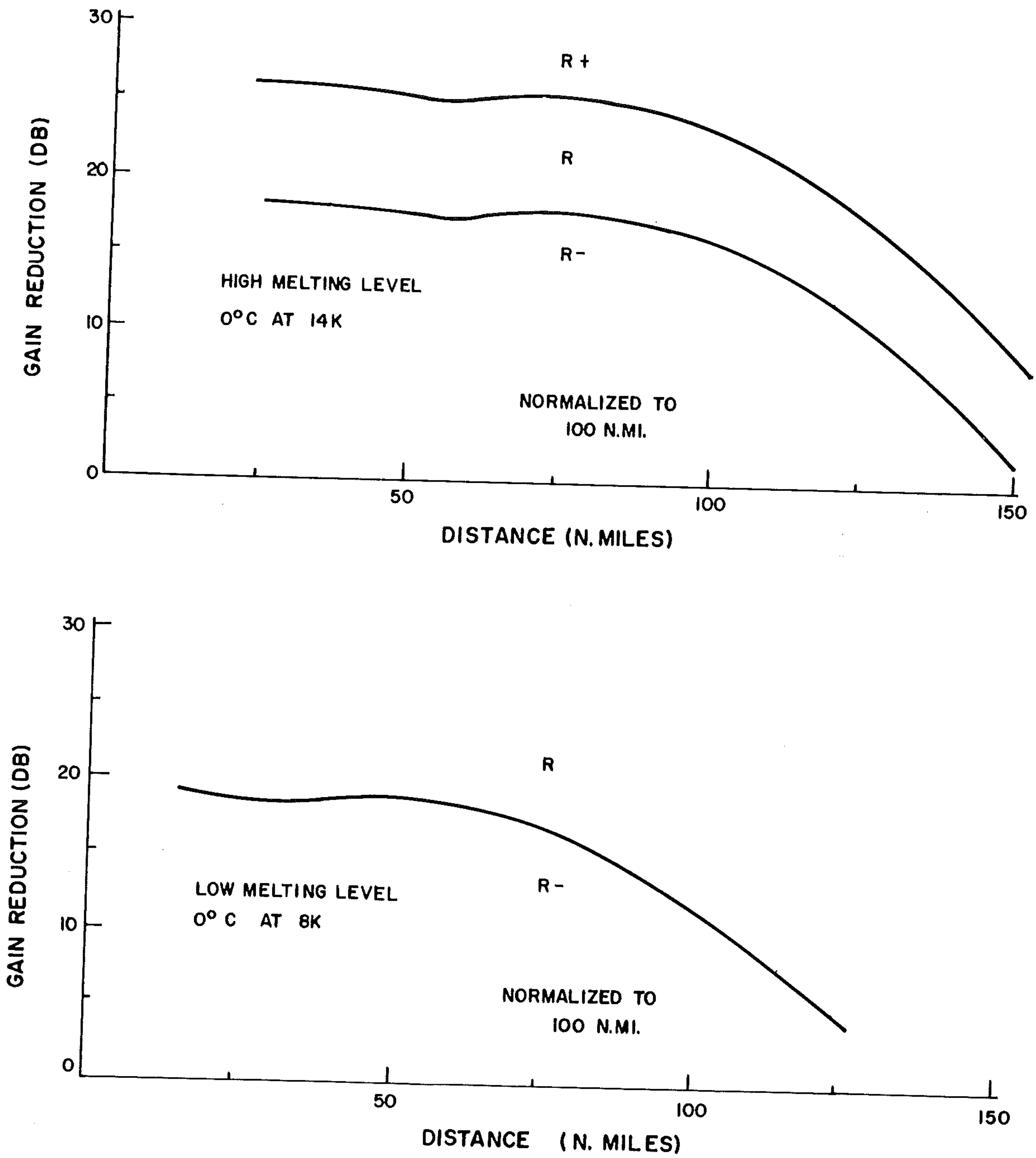

Figure 7-4. Performance of WSR-57 Radar in Two Model Rainstorms with Stratiform Precipitation. Antenna Elevation: 0.5°

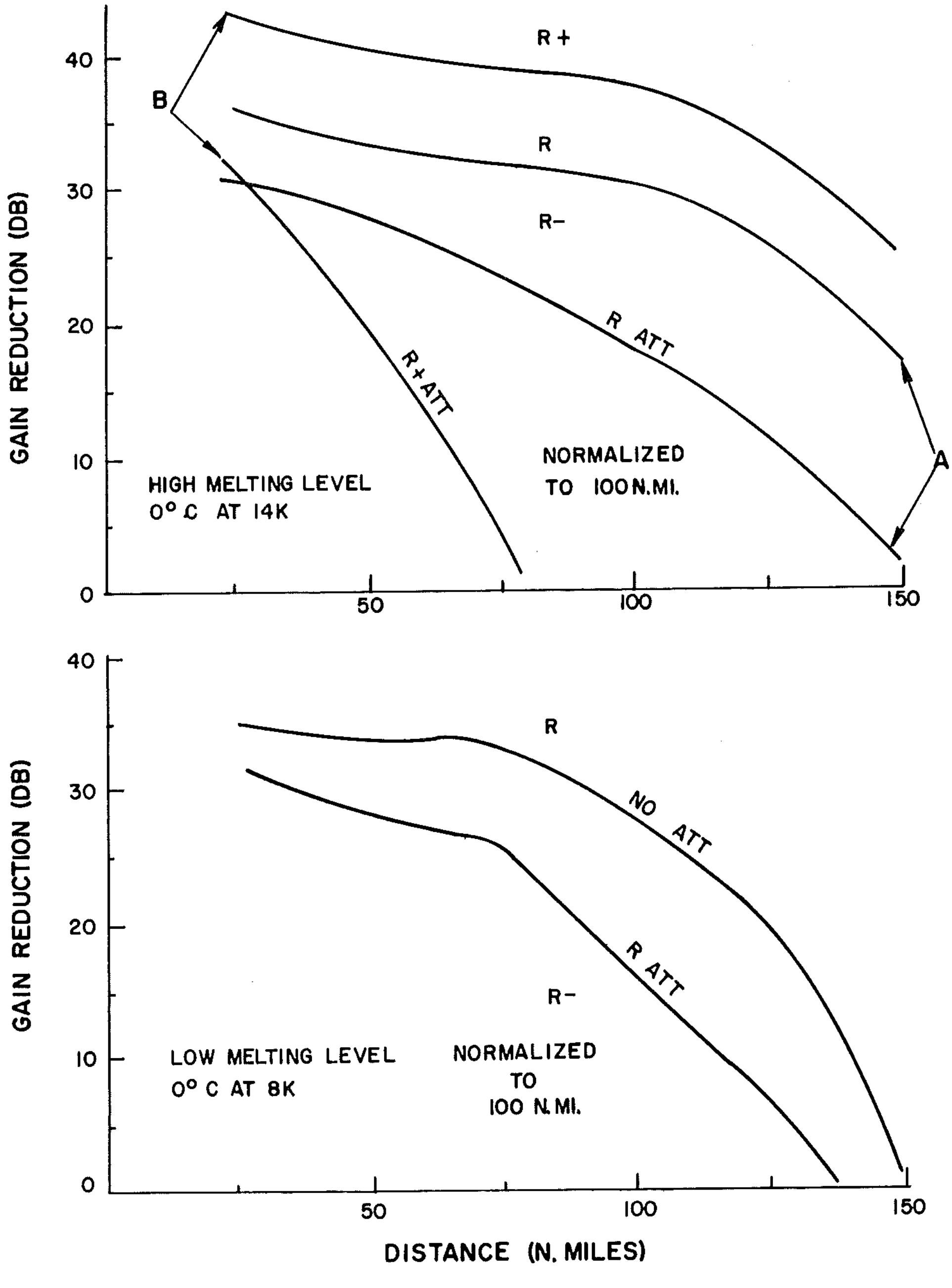

Figure 7-5. Performance of CPS-9 Radar in Two Model Rainstorms with Stratiform Precipitation, Showing Effects of Attenuation by Moderate and Heavy Rain. Antenna Elevation: 0.5°

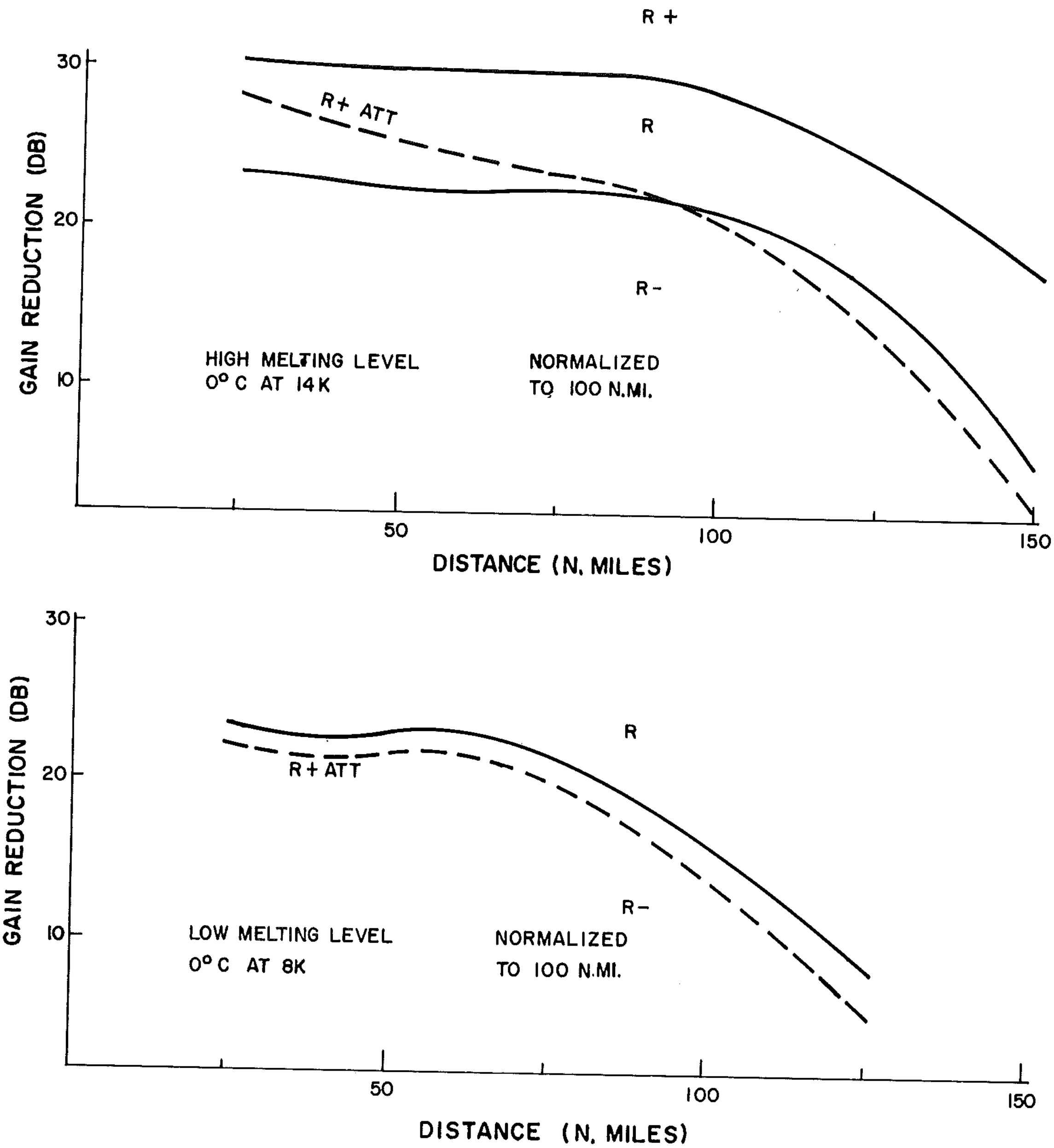

Figure 7-6. Performance of AN/FPS-77 Radar in Two Model Rainstorms with Stratiform Precipitation Showing Effects of Heavy Rain Attenuation. Antenna Elevation: 0.5°

Figure 7-6 for the AN/FPS-77 shows that the gain reduction criterion for detecting moderate rain is 20 to 22 db out to 75 miles for the low melting level and out to about 100 miles for the high melting level. Attenuation due to moderate rain (0.1 in/hr) is only 2 to 3 db in the first 100 miles and so is omitted from the upper set of curves. Heavy rain attenuation is about 8.5 db per 100 miles and under such circumstances ambiguity in measurements could occur. However, measurements without about 50 miles would very rarely be seriously affected by attenuation.

7.3 SUMMARY

In summary, the CPS-9 is more sensitive than the AN/FPS-77 or WSR-57 in detecting distant precipitation. The WSR-57 is superior to the CPS-9 in detecting rain through moderate rain. The AN/FPS-77 is somewhat more sensitive than the WSR-57 in detecting distant precipitation and is seriously affectected by attenuation only in very heavy rain. The relative capabilities of the AN/TPQ-11 are discussed in detail in Air Weather Service TR 180.[2]

7.4 REFERENCES

1. Bigler, S. G., and M. W. Brooks: Standardization of Performance of WSR-57 Radars. Proc. Tenth Weather Radar Conf. 330-334, 1963

2. Hdq., AWS: Preliminary Operational Application Techniques for AN/TPQ-11. TR-180, 1964

Chapter 8

RADAR COMPOSITING

8.1 GENERAL

The foregoing discussions, explanations and techniques, in general, have been based upon the utilization of a single radar for application of local observation, interpretation and forecasting. It is quite practical to consider the data from more than one radar and apply the multiple radar data in a composite form.

Composited radar data, analyzed by techniques similar to the analysis of data from a single radar can provide observation, interpretation and forecasting for areas proportional to the number of individual radar data used to make up the composite. Any number of radar data sources can be composited to supply any degree of synoptic coverage desired.

The Weather Bureau, in conjunction with Air Weather Service, has established a National Radar Reporting Network. The Radar Analysis and Development Unit (RADU) of the National Severe Storms Forecast Center at Kansas City prepares and transmits a facsimile composite of the radar reports from the network radars. Each hour a narrative hourly radar summary, SD-1, is transmitted on Service A.

8.2 MANUAL TECHNIQUES

Every hour, at 45 minutes past the hour, each Weather Bureau radar station is called on the RAWARC circuits and given an opportunity to file their radar report (RAREP). In addition, at approximately the same time, the Air Weather Service reports (CPS-9 radar stations) are forwarded to Kansas City from the AWS communication center at Tinker Field, Oklahoma, via a direct line to the 42nd Detachment, 8th Weather Group, U.S. Air Force, co-located with the Weather Bureau Office.

These reports are used to prepare an hourly radar plotting chart, with the Weather Bureau and Air Weather Service reports being given equal weight as to echo coverage and location, but auxiliary information, such as echo type and intensity, tops and movement being weighted toward the information provided by the Weather Bureau reports in cases of disagreement. The manual plotting of the reports requires from ten minutes to occasionally 40 minutes, depending upon the amount of radar activity occurring. With a heavy workload, the plotting chart is cut into two sections; two men plot simultaneously, and the sections are pieced together for preparation of the SD-1 hourly radar summary and facsimile chart.

In order to meet communications deadlines, the hard copy of the SD-1 must be filed by 30 minutes past the hour, and, therefore, an arbitrary deadline for completion of the plotting has been set at 20 minutes past the hour in order to provide time for preparation of the SD-1. The facsimile chart (ADUS) is prepared from the radar plotting chart by use of a reflection type reducing machine which reduces the image of the large-scale work chart to the facsimile scale and it is traced directly onto the facsimile chart. Auxiliary data is then added to provide the maximum amount of information with maximum legibility.

Once the radar chart is completed, the SD-1 is prepared by the RADU personnel. Since there is frequently some disagreement between overlapping reports, it is necessary for the analyst to interpret the data with regard to recognized radar meteorological principles.

Due to the processes involved, the facsimile chart quite naturally provides a much more detailed and accurate picture of the radar patterns than the SD-1. Echoes can be traced in detail on the facsimile chart, while they must, in the interest of brevity, be grouped together into larger areas for the SD-1. At the present time, 13 radar summary charts are being transmitted directly from Kansas City on the national facsimile circuit. Eight of these are full-size three-hourly charts which correspond in time with the synoptic surface maps. Five intermediate radar summaries, each of which is allotted six minutes, are transmitted but they depict only areas of significant echoes.

8.3 AUTOMATED TECHNIQUES

At the present time, little, if any, automation is employed in the observation, interpretation and forecasting of weather from radar data. Most of the functions utilized in the manual techniques described in Section 8.2, however, lend themselves to various degrees of automation. Recent studies [1] have resulted in a preliminary design for the automation of the observation, interpretation, compositing and transmission functions associated with weather radar data. In addition, through more recent efforts [2] some degree of automation is practical in forecasting from weather radar data.

The preliminary design cited [1] removes essentially all subjective considerations in acquiring and handling radar data, and replaces many with objective consideration. For example, each radar is calibrated with a reference target thereby removing the subjective function of reading test equipment which in turn has been subjectively calibrated. Reference targets for each radar site would be identical. A basic requirement in automation is a method of tagging specific samples of weather radar data with relatively true intensity or Z values. This is accomplished through quantizing the radar signal output and the use of range normalization in the radar receiver. Because more than one location is usually interested in the weather radar data, digitizing this data provides a convenient method for transmission and processing for forecasting. In addition, compositing multiple radar data for larger areas (other than local) is more readily accomplished by digital methods. A device for digitizing weather target position, intensity and maximum height presently exists as a laboratory model. (See Section 9.2.)

Utilizing a radar data digitizing device, timing logic would provide an automatic sequence as follows:

1. Radar set calibration check (go - no go).

2. Volume data acquisition (azimuth, height and intensity of weather radar targets).

3. Storage of acquired and tagged radar data.

4. Programmed search of significant radar data.

5. Automatic interpretation of radar data.

6. Forecast probability of arrival, intensity and duration of precipitation.

7. Printout of radar forecast.

In addition, network operation, including multiple radar station reporting, would include the additional sequence of processed data transmission when interrogated (roll called) or automatically when ready. The operation, being automatic, would require a minimum of time (relative to subjective methods) for updating. Separating the calibration and volume data acquisition functions (which could be simultaneous for multiple stations in a network and necessary for relative data comparison), data handling time would be of the order of seconds for each station.

8.4 REFERENCES

1. Speed, D. K.: Objective and Automatic Methods for Synoptic Utilization of Multiple Weather Radar Data. Report WSC-F-9, United Aircraft Corporation, 1962

2. United Aircraft Corporate Systems, Weather Systems Center: Operational Application Manual for the Radar Meteorological Set AN/FPS-77(V), Report M-55, 1964

Chapter 9

RECENT ADVANCES IN RADAR INSTRUMENTATION TECHNIQUES

9.1 CONSTANT ALTITUDE PLAN POSITION INDICATOR (CAPPI)

Both the horizontal and vertical structure of precipitation may be of operational importance, therefore, it is frequently desirable to examine both PPI and RHI displays. When storm echoes are extensive, RHI displays at different azimuths may be required. Alternatively, the use of CAPPI techniques presents a PPI display at different constant altitudes, which then allows a three dimensional interpretation of the echoes. The displays in some storms are made for as many as six different altitudes which are usually spaced 5,000 or 10,000 feet apart (Fig. 9-1).

The CAPPI display is generated by PPI scanning at successive angles of elevations, in steps of one beam width. The geometry of the scans for CAPPI displays at 5,000 and 15,000 feet is shown in Figure 9-2. It is seen that at short ranges, less than about 30 miles, the successive radar scans are sampling echoes within about 1,000 feet of the desired level; at 70 miles some of the echoes may be 4,000 to 5,000 feet above or below the selected level. The information for each level may be stored either on film or electronically by means of storage tubes. This permits conversion from the azimuth scan of the PPI to a linear scan and allows display by conventional TV or facsimile techniques.[1] In some CAPPI techniques, several levels may be recorded simultaneously by the use of separate cathode ray tubes each with a corresponding storage device.

9.2 AUTOMATIC RADAR DATA PROCESSING

Thanks to a high degree of sophistication in present-day weather radars, such as the WSR-57 and the AN/FPS-77, weather radar data lend themselves to a high degree of automatic processing, provided an objective method of absolute calibration is incorporated. Processing in this instance means conditioning of the raw radar data for rapid dissemination and assimilation and not the development of forecasts. Raw radar data as used here imply information in the form of video voltage output from the radar receiver that has not been altered or modified. Processed data imply any modification of the raw data.

Up to the present time most applications of radar information utilize the raw form of the data as typically displayed on the PPI, RHI, and A-scope. In the case of PPI and RHI displays, the brightness of the phosphor of the cathode ray tube varies in accordance with the received signal intensity. The phosphor is limited in brightness to an approximate dynamic range of 10 to 12 db. Consequently the maximum number of adjacent "grey" scales on a single display, normally resolvable to the human eye, is limited to four and possibly five. In the case of the A-scope

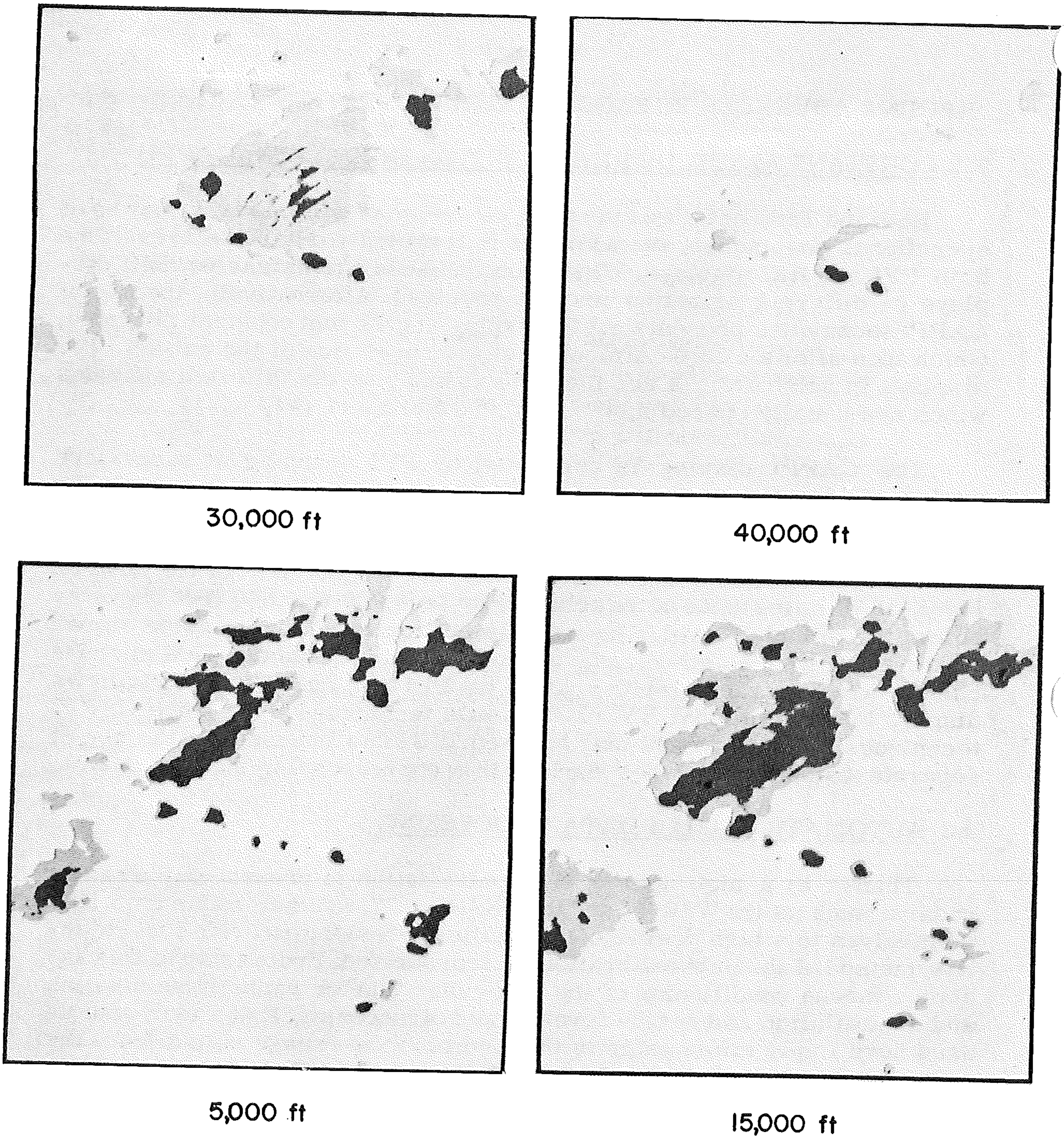

Figure 9-1. CAPPI Presentation of Normalized Radar Echoes at Four Height Levels and Three Intensity Levels in Vicinity of Montreal, Canada, 7 August 1963, 1450E. Photographic Scan Conversion, Facsimile Output. McGill University CPS-9 Radar, Logarithmic Receiver. [1]

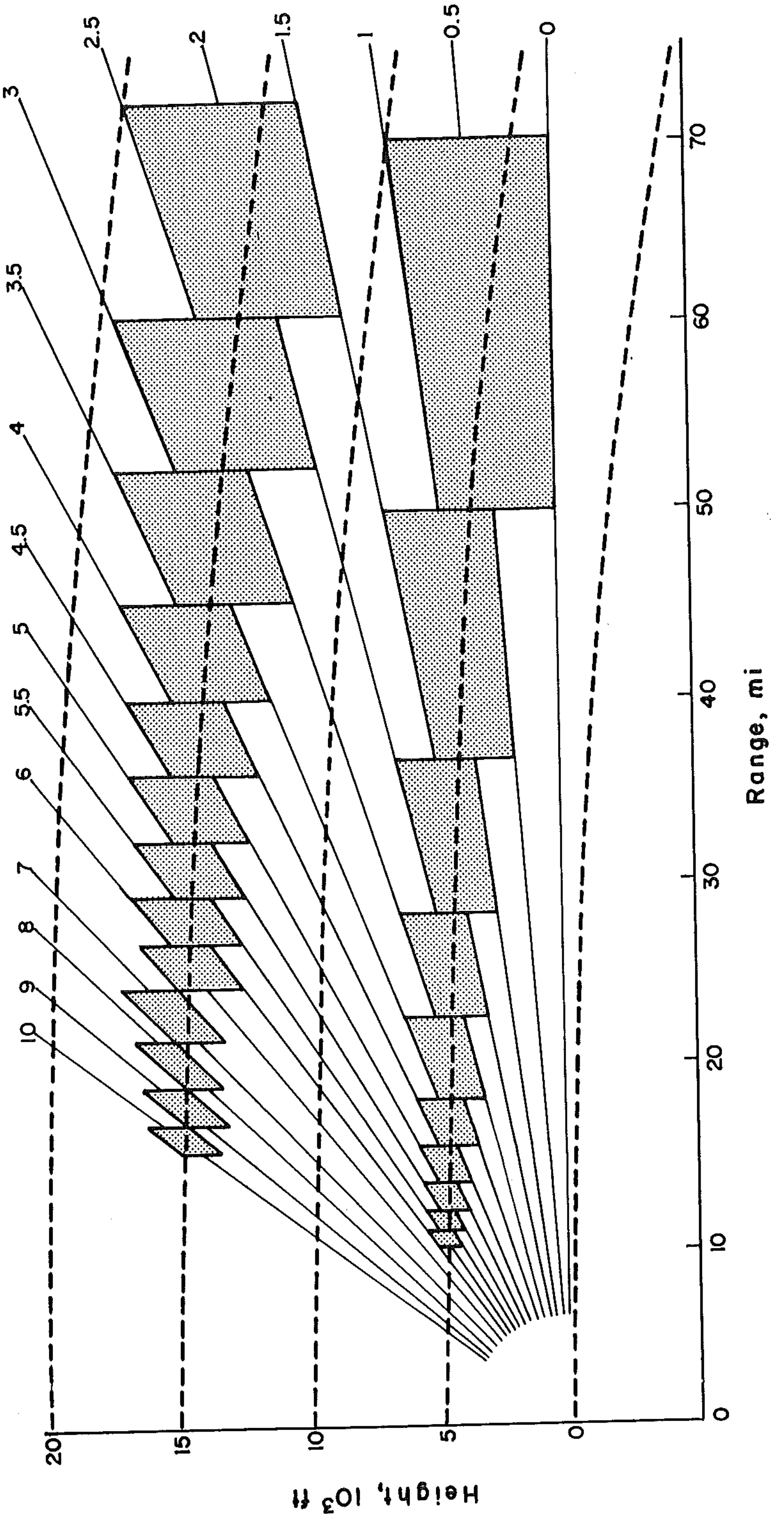

Figure 9-2. Geometry of CAPPI Display for 5,000 and 15,000 ft. Levels[1]

display signal, intensity is manifested as an ordinage excursion and thereby is not limited in dynamic range. However, the A-scope does not provide azimuth or elevation information. Range information for weather targets in different azimuths and elevations is obtained by a comparatively tedious and time-consuming process.

Typical logarithmic characteristics in the WSR-57 and AN/FPS-77 receivers will handle a range from zero to approximately 70 db. Through the incorporation of range normalization, which provides range squared correction, and the use of the logarithmic receiver characteristic, any weather target signal at any range will be reproduced as a true relative video signal that can be processed manually or automatically. This video signal is a voltage proportional to the radar sampled weather intensity or equivalent to the Z value of the weather target. It is this feature which permits automatic processing of radar data in terms of echo intensity.

Several prototype weather radar digitizers exist. Techniques in arriving at similar outputs and/or displays vary. Sample digitized outputs of intensity and height-tagged data are shown in Figure 9-3.

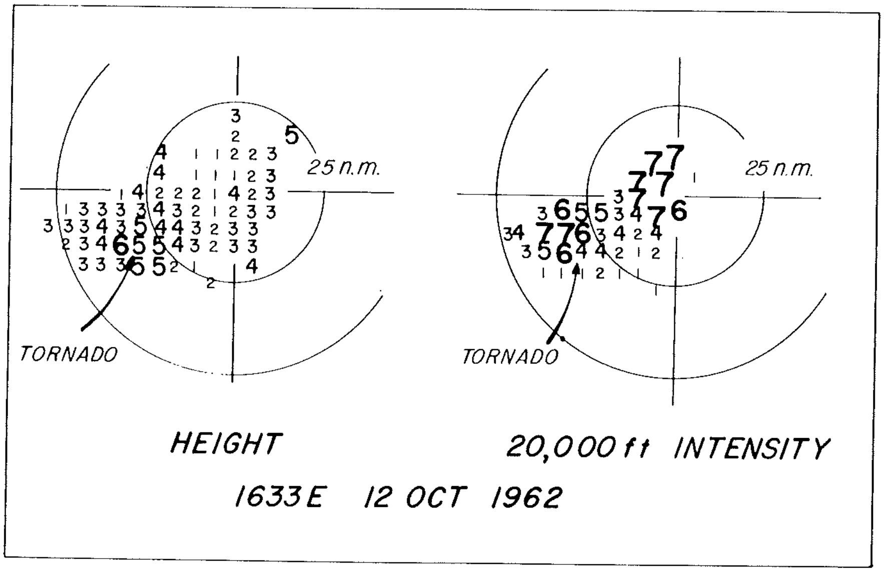

Figure 9-3. Sample of Digitized Printout from Radar Data Processor "STRADAP". At Left Echo Height in 10,000 ft. Classes. At Right Intensity at 20,000 ft. by 6 db Classes. Digits Represent Maximum Value in 5 x 5 n. mi. Squares. [2]

9.3 DOPPLER RADAR AND FLUCTUATIONS

It is well known in the field of optics and acoustics that objects moving away from or towards an observer cause a shift in frequency. Thus astronomers recognize receding stars by the characteristic "red shift" or increase to higher wavelengths.

Doppler radar operates on the principle that the echo from a target moving with a relative velocity v forward or away from the radar will be shifted in frequency by an amount $f = 2v/\lambda$, where λ is the wavelength of the transmitter signal; f is positive for motion toward the radar and negative for motion away from the radar. Hence, Doppler radar measures the frequency shift of the returned signal which may then be calibrated in terms of relative velocity. If v is expressed in knots and λ in cm, and f in cycles per second, then

$$f = 103v/\lambda$$

Although radars may be designed to measure both the sign and the magnitude of the shift, many Doppler radars cannot distinguish sign; therefore, the observer must interpret from other information whether the target is advancing to or receding from the radar.

Doppler information may be obtained with either CW or pulse radar. CW radar has the advantage of simplicity and less expensive equipment but because of leakage between transmitter and receiver which limits its sensitivity, the use of two antennas is required. The Weather Bureau has utilized CW Doppler radar for tornado detection.[3] However, CW is incapable of providing range information without extensive sophistication. Pulse Doppler radar provides the range information but requires a high PRF, which may cause range ambiguity.

A block diagram of a typical pulse Doppler radar is shown in Figure 9-4. The chief modification from this conventional pulse radar is the provision of a reference frequency f_{Ro}, which, combined with the local oscillator frequency f_{Lo}, is coherent with the transmitted signal. The return signal $f_R = f_{Lo} + f_{Ro} + f_D$ where f_D contains the Doppler information, is then compared with the reference frequency, so that only the information contained in f_D is displayed.

The echo intensity from precipitation, or any moving target, is subject to rapid short period fluctuations, which are apparent on an A-scope. When the echo intensity is averaged over a period of about a second, it is relatively constant and is a measure of the reflectivity of the precipitation. The shorter period fluctuations provide information on the relative motions of the individual scatters in the beam. In practice, for reasons of

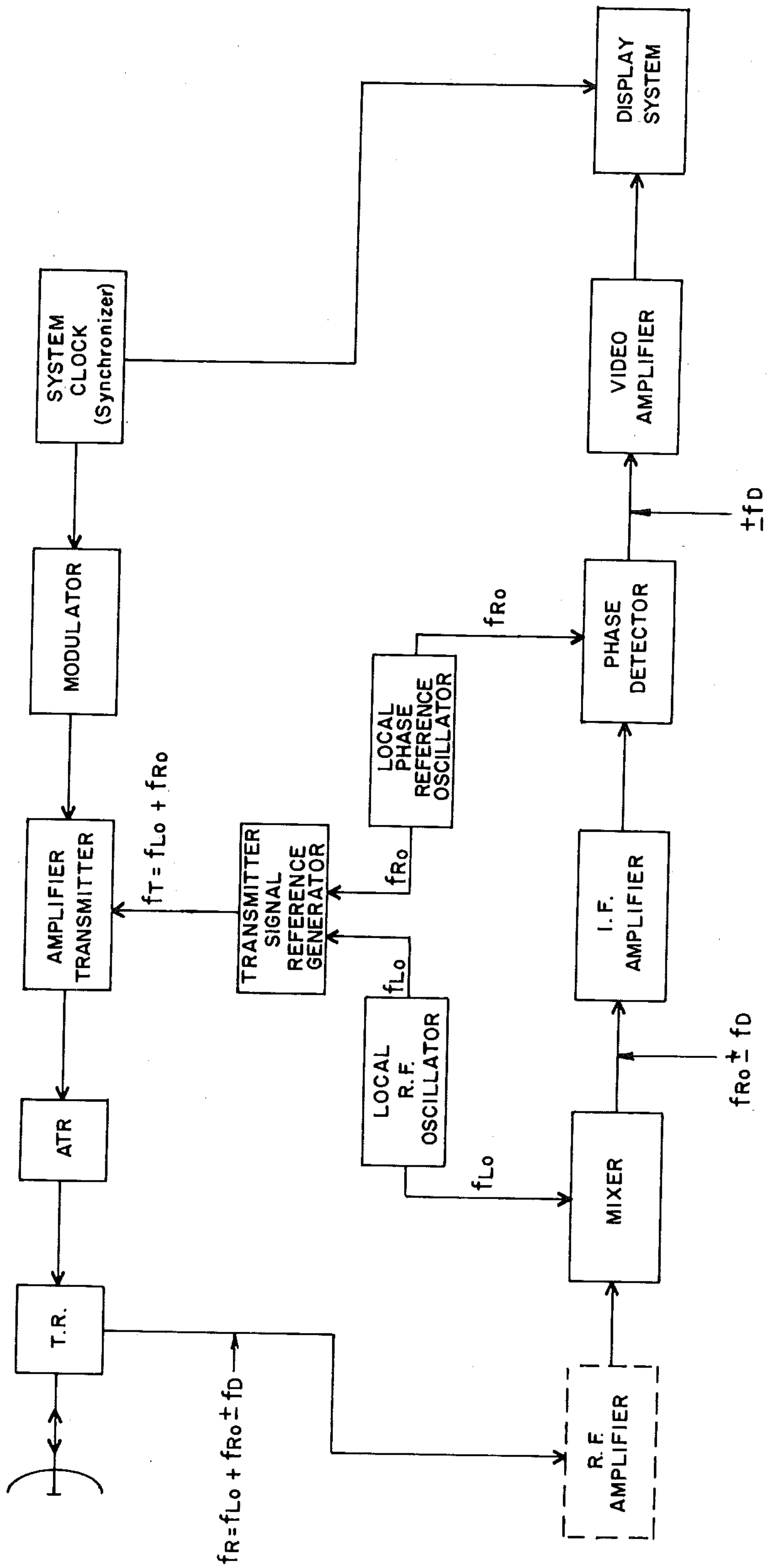

Figure 9-4. Block Diagram of a Typical Pulse Doppler Radar Using a Klystron Power Amplifier.

economy, only statistical properties of these fluctuations are measured and from these the distribution of velocities of the precipitation particles may be inferred.

Fluctuations of the return signal from moving targets occur both in phase and amplitude. Doppler radar recognizes the Doppler component by measuring the change in phase of the return signal. This is done by comparing the phase of the return signal with that of a reference signal that is coherent with the transmitted frequency. For this reason the radar is said to be "coherent." Conventional pulse radars are incoherent. However, even on incoherent radars, a measure of the statistical properties of the amplitude fluctuations can provide information on the motion of the target. The addition of certain equipment such as a frequency meter or R-meter[4] to a conventional radar allows such measurements.

The radial velocity of precipitation measured by Doppler radar is given by

$$v = u \cos\alpha \cos\beta \pm w \sin\alpha$$

where

u is the wind velocity

w is the fall velocity of the precipitation

α is the angle of elevation

β is the azimuth angle with respect to the wind direction

In widespread rain Probert-Jones[5] obtained the horizontal wind in snow above the melting layer by assuming a fall speed of 1 m/sec and by measuring the Doppler wind at two azimuths 20° apart. His accuracy was estimated at 2 m/sec. The mean wind over a wider sector was obtained with greater accuracy by taking readings every 10° around the estimated wind direction over a sector of about 120° and averaging the five largest values, then making a small correction for the cosine term. An estimate of the convergence within a circle around the radar was obtained by taking 36 readings every 10° at a constant range.[6]

If the wind is assumed to be horizontally homogeneous in all directions within range of the radar, then both the horizontal wind and the particle fall velocity may be obtained. When scanning at constant range and angle of elevation in different directions during widespread rain there will be two maxima; one in the upwind direction, the other in the downwind direction.[7]

If the radar cannot distinguish sign, the maximum in the upwind direction will be greater because the fall speed adds to the Doppler component, while downwind it subtracts. The mean of the two maxima gives the horizontal wind velocity times the cosine of the angle of elevation. The fall velocities of the particles may then be determined. If the data are continuously recorded the width of the trace also gives information on wind shear and turbulence at low angles of elevation or the fall velocity spread at angles of elevation near the vertical.

Doppler radar is less suited for measuring the wind in convective storms. In these situations horizontal homogeneity of the wind field is less likely to be valid. If horizontal homogeneity is assumed and measurements on two or three convective storms at different azimuths are obtained, some estimate of the mean wind velocity may be obtained. Alternatively observations of the same storm from different directions by two or three radars enables wind to be measured more accurately.

Perhaps the most important application of pulse Doppler radar is in tornado detection. For a pulse length of a few hundred feet, the entire circulation of the tornado may be contained within the pulse volume of the radar. With winds exceeding 100 knots, the Doppler spectrum would be characterized by tremendous breadth and roughly equal speed across zero velocity.

Range and velocity ambiguities arise when measuring high wind velocities. In order to properly identify a frequency f the phase must be sampled at a frequency of at least 2f. Because it is sampled at the pulse repetition frequency (PRF), then the maximum frequency which can be measured is

$$f_{max} = \frac{PRF}{2}$$

Because

$$f_{max} = \frac{2v_{max}}{\lambda}$$

then

$$v_{max} = PRF \frac{\lambda}{4}$$

If the entire circulation of a tornado is encompassed by the beam, the maximum velocity is twice this value. The maximum range is given by

$$r_{max} = \frac{c}{2PRF}$$

Hence for long maximum ranges a low PRF is desirable while for measuring high velocities a high PRF is required. Thus the detection of a 100 knot wind at C band requires a PRF of about 3700 pulses per second, which limits the maximum range of a wind velocity in one direction to 22 miles. A target at 35 miles would then appear on the radar at 13 miles. Range ambiguity may be resolved by using two PRFs or by "randomizing" the PRF.

The echo intensity from tornadoes, as measured by conventional non-coherent pulse radar, is subject to rapid fluctuations which may be measured by conventional radar after suitable modification. A system may be designed which produces an alarm signal when fluctuations indicative of winds greater than 100 knots occur.

9.4 REFERENCES

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2. Atlas, D., H. J. Sweeney, and C. R. Landry: STRADAP (STorm RAdar DAta Processor) Performance. Proc. Tenth Weather Radar Conf., 377-383, 1963

*3. U.S. Weather Bureau: Weather Surveillance Radar Manual. Washington, D. C. 1960

4. Rutkowski, W., and A. Fleisher: R-Meter: An Instrument for Measuring Gustiness. Weather Radar Research Report, No. 24, MIT, 1955

5. Probert-Jones, J. R.: The Analysis of Doppler Radar Echoes from Precipitation. Proc. Eighth Weather Radar Conf. 347-354, 1960

6. Caton, D. G. F.: The Measurement of Wind and Convergence by Doppler Radar. Proc. Tenth Weather Radar Conf. 290-296, 1963

7. Lhermitte, and D. Atlas: Precipitation Motion by Pulse Doppler Radar. Proc. Ninth Weather Radar Conf. 218-223, 1961

* References marked with an asterisk (*) are recommended for general reading.

Chapter 11

RADAR HYDROLOGY

11.1 INTRODUCTION

This chapter contains operational guidelines for the radar operator pertinent to the River and Flood Prediction and Warning Services of the Weather Bureau. These guidelines supplement the observing and reporting instructions contained in Part A of this manual. This chapter also serves as a general guide on radar-hydrology and has information on measuring precipitation by radar with respect to the display and interpretation of the data for hydrologic applications.

11.2 GENERAL

Reliable river forecasts are essential to efficient management of water resources just as warnings of floods are essential to the protection of lives and property. These warnings and forecasts require observations and predictions of rainfall. Radar estimates of rainfall intensity are used in river forecasting and warnings of floods.

The fact that radar is capable of detecting and locating precipitation continually makes it valuable to the operations of meteorologists and hydrologists. Radar data are most effective when coordinated with a network of rain gages, but in many instances may be the only observation of precipitation. The application of radar is becoming an essential adjunct to precipitation gage networks. Its immediate application holds most promise in detection of intense rainfall of flash flood potential. A new development is the automatic detection and processing of radar data in terms of rainfall.

11.2.1 Flood Classification

Flood situations are as highly variable as the storms that produce them. The use of radar depends to a great extent upon the type of storm.

Storms may be classified into two general categories: (1) those producing heavy, short duration rainfall over relatively small areas, or (2) those producing widespread continuous rains. In the first type, or flash flood, the time element is paramount. Concentration times are short, and flooding occurs much sooner after the cessation of rainfall, or even while the storm continues. The flooding that accompanies the second type concerns, for the most part, the main stems of large rivers where the water is routed downstream by means of standard procedures.

However, a combination of these storm types can occur resulting in a flash flood condition of worse magnitude than the first type. For predicting these types of flash flooding, radar observations have proven most useful.

Radar operators should be alert for high intensity, short duration echoes from precipitation associated with hurricanes moving inland. Under these circumstances, a large number of small drainage basins may produce floods. Radar is particularly useful in delineating the basins where heaviest rain is falling, thus allowing the forecaster to alert those specific areas.

11.2.2 Spatial Variations in Storms

Variability in storm intensity is a pertinent feature lacking in the evaluation of present precipitation reports. To a limited extent Weather Bureau first-order stations give a fair indication of intensity; however, these stations fall short in providing the necessary information to the river forecaster. Weather Bureau first-order stations report current precipitation rates as light, moderate, or heavy. The heavy rate of fall is defined as 3/10ths of an inch per hour or more, with no way of indicating how much more.

Radar is quite sensitive to variations in intensity of rainfall and marked variations may be noticed within a storm. One need only study a recording rain gage chart to see the temporal variability of rainfall at a given point. In dealing with large areas the problem is very complex; but with radar more nearly complete coverage of the storm is possible.

11.2.3 Hydrologic Range

The hydrologic range of a radar is defined as the maximum range in which the relationship between the radar echo intensity and rainfall intensity as measured by precipitation gages remains reasonably valid. This relationship has been shown to be good out to 60 n. m. by Wilson[1], with decreasing accuracy out to 100 n. mi. Usually a long wavelength radar (10 -cm) is employed because a shorter wavelength is significantly attenuated in passing through heavy precipitation.

11.3 RADAR-HYDROLOGY PROGRAM

Among the several responsibilities of the Weather Bureau are the preparation and issuances of River and Flood Forecasts and Warnings. A Weather Bureau program to minimize the loss of life and property caused by flooding has been in existence for over 50 years. With the advent of radar into the Weather Bureau following World War II the program expanded to include effective utilization of radar[2], for early warning of heavy rains that could lead to flash flooding[3] and more recently in direct assessment of rainfall amounts for use in river predictions and water management. The Radar-Hydrology Program is in direct support of these services.

11.3.1 Radar Operator Responsibilities

The radar meteorologists should be trained in the operation of the local river district program:

A. Certain WSR-57 stations with little or no river program (e.g. Galveston) should cooperate in local flood warning programs, advisory service to River Forecast Centers (RFC) or River District Offices (RDO) within the area of coverage of the radar.

B. At stations having a river program, the radar operators should participate in the river district work to whatever extent is necessary to accomplish the following:

(1) become familiar with the river drainages, areas subject to flash-flooding, headwater advisory forecast points, precipitation reporting networks, and designated community flash flood systems.

(2) aid in determining areas where additional rainfall reporting stations (visual, wedge, alarm gages) should be established to complement existing networks.

(3) collect data, during a heavy rain situation that may result in flash flooding, for radar analysis and interpretation. This may be collected by contact with RDO's, direct calls to substation observers, or telemetered rain gages or use of MRT's.

(4) work with RFC's, particularly those with computer capability, toward operational determination of areal rainfall distribution by radar.

Through a constant appraisal of the precipitation distribution during the actual occurrence of storms, the radar operators will get the "feel" of the relationship between radar echoes and precipitation rates. This will necessitate using all features that have been built into the radar for this purpose; echo contouring; use of the attenuators for reflectivity relationships; evaluation of intensity from the A-scope; offset PPI for careful study of storm structure; RHI for height vs. intensity, rate of build-up, and reflectivity relationships; use of STC to correct for range attenuation; and use of photography in the evaluation of radar echoes for comparative analysis with rain gage data.

11.3.2 Techniques

To maximize the usefulness of radar for hydrology, procedures must be developed that will give quantitative and representative results. The techniques employed by the radar operator to describe and present the information to the hydrologist will depend on whether the hydrologist has direct access to the radarscope or has to depend on coded information. In the development of these techniques the requirements of the RDO and RFC should be made known to the radar station. With this information the radar staff can then design an effective radar-hydrology program to best serve the river basin of concern. The following guidelines are offered to assist in that task.

1. Radar operators should be fully aware of the "Radarscope indicators of Possible Flash Floods."

2. Each radar station should have on hand adequate PPI overlays of the acetate and paper types.

3. Each radar station must receive and know how to use available "Headwater Advisories" of their area of concern.

4. Each radar station should have an adequate wall display map on which rainfall amounts carried in the advisories can be plotted for ready reference.

5. Devise at each radar station a method whereby radar estimates of rainfall are plotted as a means of maintaining watch over the situation during periods of heavy rainfall.

6. Each radar station staff member must know the River District Office it serves and the person or persons at the RDO to contact regarding river service.

7. A list of cooperative rainfall observers should be posted in the radar room for use in verifying reports of indicated areas of heavy rainfall.

8. A plan of action needs to be prepared for the radar-meteorologist to follow when a suspected flood situation is developing.

11.3.2.2 <u>Radarscope Indicators of Possible Severe Storms Contributing to Flash Floods</u>

1. Echoes of moderate or stronger intensity.

   Echo speed less than 40 knots.

   Tops greater than 40,000 feet.

   Cell diameter of 10 miles or more.

2. PERSISTENCE - Little echo movement for 2 or more hours.

3. Hurricanes

   Thunderstorms imbedded in spiral bands.

4. Train echoes - (echoes repeatedly traversing the area).

5. LEWP echoes (Line Echo Wave Pattern).[4]

6. Converging echoes.[4]

7. Rapidly growing echoes.

8. Echoes taller than surrounding echoes by more than 5,000 feet.

9. Echo edges sharply indented or scalloped.[4]

11.3.2.3 <u>Interpretations</u>

1. BRIGHT BAND - MELTING LEVEL (USE RHI SCOPE)

   a. Estimate elevation in mountains where boundary between rain and snow exists.

2. RAIN or SNOW - SNOW LINE (USE A SCOPE)

   a. Used in conjunction with (1) to determine rain/snow boundary.

   b. Important when rain falling on snow-pack.

3. STRONG ECHOES - HEAVY RAINFALL (USE PPI & RHI SCOPES)

   a. Rapidly growing echoes, converging echoes, or those higher than their surroundings can produce heavy rainfall.

b. Oddly shaped echoes with indented or scalloped edges or those associated with the discontinuity of LEWP's are potential heavy rain producers. These echoes are often associated with intense thunderstorms.

c. Orientation of certain storm systems create a situation where one echo after another passes over the watershed in a relatively short time period with resultant flooding.

4. FAST MOVING ECHO - WIND DAMAGE (USE PPI SCOPE)

a. May indicate high reflectivity but because of short time over any area flash flood potential not high.

5. HURRICANES - SPIRAL BANDS (USE PPI & RHI SCOPES)

a. Tornadoes or

Thunderstorms accompanied by heavy rainfall.

b. Rain gushes superimposed on steady rain may cause flash flooding.

11.3.3 Intensity Contouring

The simplest analysis technique involves periodic tracing of echo positions on transparent acetate PPI overlays which show river basin boundaries in the appropriate range scale. Qualitative estimates can be made of the instantaneous storm intensity on the basis of echo reflectivity alone, i.e., light, moderate, strong or very strong. If communications facilities permit, corroborating evidence on storm intensity should be used for subjective "calibration" of the radar displays. Areas with strong echoes are receiving heavy accumulation and those concerned should be alerted for possible flooding of the streams draining the basins when these echoes persist.

Those offices not colocated with radar, and having a requirement that RAREPS do not satisfy, should make arrangements to receive periodic briefings (telephone or RAWARC) as the situation warrants. This type of briefing has proven to be a very valuable supplement to the RAREPS for the hydrologist.

11.3.3.1 Manual Step-Gain Procedure

Place a 125 n. m. hydrologic overlay over the PPI and step the LIN attenuator through several db intervals, contouring the echoes every

30 minutes, to an hour. Successive tracings of the scope display can be superimposed to determine the areas affected, the direction of storm motion, and the area-intensity relationship. Alternatively, the tracings may be made on a single sheet of acetate, using different colors for the different times.

Copies of the overlay should be regularly posted in the briefing room for the use of all forecasters and other interested persons. This procedure is one of the easiest ways to keep those concerned routinely advised.

11.3.3.2 Video Integrator Processor

The Video Integrator Processor (VIP) currently under test and development automatically displays several levels (5-10 db intervals) of contoured echo intensity and will facilitate the contouring of radarscope overlays. The procedures outlined in the above paragraphs still apply for tracing contours from the PPI scope onto the overlays.

11.3.3.3 Photography

Two types of photographic records are available from the camera system employed with the WSR-57 by the Weather Bureau. The first is the time-lapse 35 mm film record which is available for study and review only after processing. The second is the Polaroid photograph where within seconds of exposure either a print or transparency is available for viewing or projection purposes. Because of its real-time value the Polaroid camera system has definite application in daily operations.

11.3.3.3.1 Multiple Exposure Photography

Multiple exposure photography[5] consists of re-exposing the same piece of film at predetermined intervals. The Polaroid camera shutter is opened at each of the desired times for the full revolution of the antenna. The picture obtained is an integration of the total number of exposures in which the brightest areas on the film represent either the most intense precipitation or that of greatest echo persistence.

This technique provides areal coverage of the precipitation pattern over a predetermined time period. The information has been found to be of most use on-site where projection equipment is available to view the echo images directly from the Polaroid 46L film. It should be noted that very little intensity information is available from this type photograph. Optimum camera settings can best be determined by experimentation, however, exposure intervals of 10 minutes for 2-hour periods at f 1/6, and f 11 for one hour are suggested.

11.3.3.3.2 Single Polaroid Exposures

Single Polaroid exposures at f /4 of particular events can be very useful to the hydrologist. Pictures can be obtained in print or transparency form to study, in real-time, the storm's progression and growth.

Comparison of the transparency with rainfall reports can be made by tracing the projected echo images each hour on a wall map of the basin.

11.3.4 Sources of Hydrologic Data

Primary sources for obtaining precipitation data may be separated into two categories: (1) operational - data immediately available, (2) climatic-data obtainable from NWRC.

A. There are a number of data sources for precipitation analysis of radar information for hydrologic purposes.

(1) First-order Weather Bureau Stations:

Hourly Wx - data very subjective and indicated by symbols R, R-, R+, S, S-, S+ for broad categories. To be used to confirm presence of precipitation and type, e.g., rain, snow, hail, etc. Precipitation is reported cumulatively every 20 minutes from AMOS stations.

SM - six-hourly synoptic reports which include both six-hour and total 24-hour accumulation.

(2) Reports from second-order river and rainfall reporting stations:

SR-1 and SR-2 collectives on each circuit. Late reports are transmitted on RAWARC.

(3) Special reports:

Many agencies such as Tennessee Valley Authority, Corps of Engineers, Bureau of Reclamation, Soil Conservation Service and several states maintain rain gage networks from which reports are available. These sources should be investigated and lists compiled for local use.

Cooperative observers - arrangements should be made to call these observers within the area of coverage of the radar to verify rainfall amounts during heavy precipitation. At those stations where flash-flood networks have been established, precipitation reports may be obtained from the community representative.

(4) Emergency reports of rainfall are often available on a call basis from:

1. Police departments
2. Water pumping stations
3. Natural gas pumping stations
4. Electric power plants
5. Highway patrol radio stations
6. Radio transmitter sites
7. Reservoir sites.

Naturally all of these are not equipped with rain gages. However, if the area is sparsely covered in certain sectors, wedge-type gages could be furnished to the above locations. This would provide the radar staff with check points where the operator could call for rainfall verification in an emergency.

B. The sources of data for research are:

(1) ESSA - Environmental Data Services

Climatological Reports

(2) Tennessee Valley Authority

Rainfall in the Tennessee Valley

(3) U. S. Corps of Engineers

Special Rainfall Reports on Floods

(4) States

Water Resources Commissions and related agencies' reports.

11.3.5 Flash Flood Warning Service

Literally hundreds of communities subject to flooding cannot be adequately served by the usual flood warning system. These are communities located in the headwaters of flashy streams where the flood crest occurs only a few hours after the occurrence of intense storms. Under these circumstances, it has not been possible to collect observations, transmit them to a forecast office, prepare the forecast, and relay the warning to the threatened area in advance of flooding. A solution has been to establish cooperative community flash-flood warning systems. The community establishes a network of rainfall and river observing stations and a warning representative is appointed to collect the reports, prepare a forecast based on a procedure developed by the River Forecast Center serving the area and issue the warning. Whenever possible, the community warning representative is provided with advance warning of potentially heavy rainfall, either predicted or detected by radar surveillance. A local Weather Bureau office monitors the community plan.

The success of a flash flood warning service depends upon the detection of impending weather events and the observation of hydrometeorological factors associated with floods. As in any warning service, "time" is at least as important as accuracy, and, therefore, radar detected heavy rainfall information must be transmitted to the RDO or RFC concerned by rapid communications. Warnings must then be widely distributed to those in a position to "act." Finally, users of the service must be in a position to respond (on an individual, group, or community basis) by implementing preparedness plans to minimize the adverse effects of the predicted event.

11.3.5.1 Headwater Statement Data

As a means of alerting selected communities and Weather Bureau offices to the amount of rainfall necessary to cause flooding the River Forecast Centers issue, each week or more often if required, headwater advisories. These advisories generally relate time and rainfall to a specific river stage. There are two general types of advisories.

A. The self-help type advisory whereby the RFC or RDO provides a weekly Antecedent Precipitation Index (soil moisture index value) for use by the local flood warning representative. The API number is used with the river forecast procedure developed by the RFC and turned over to the local representative.

B. The regular headwater statement shown in Table 11-1 is prepared by the RFC and either mailed, phoned or sent via RAWARC to the appropriate RDO and some selected community flash flood representatives.

Table 11-1. Headwater Statement

OHIO RIVER FORECAST CENTER
Cincinnati, Ohio

ADVISORY FOR: PERIOD FROM 12/29/66 TO 1/5/67

COLUMBUS RIVER DISTRICT

The average 24-hour rainfall amount needed to start runoff in your district is .25 .

Station	Index	Stage (Feet)	Min. Avg. Rainfall Amounts to Reach Indicated Stage			Avg. Time to Crest From End of Heavy Rain (Hours)	Remarks
			6 hr.	12 hr.	24 hr.		
Bourneville		FS 10	0.40	0.60	0.70	12	
		13	0.90	1.10	1.40		
		16	1.50	2.10	2.50		
La Rue		FS 11	x	0.90	1.00	12	
		13	x	1.60	1.90		
		15	x	2.60	2.90		

These rainfall values are the average amounts necessary over the entire basin, above the gaging station, to produce the stage indicated. For example, if 1.60 inches of rainfall was the average amount reported during the past 12 hours by the rainfall stations above LaRue, then the expected crest of the river would be about 13 feet 12 hours later. Similarly, a rainfall of 2.10 inches during the past 12 hours above LaRue should result in a crest of about 14 feet 12 hours later.

This advisory system provides the radar operator with the calculated rainfall amounts necessary to cause flooding in critical basins. These basins have been selected based on observed storm data. However, flash flooding is no respector of assigned areas and the radar meteorologist can use these advisories only in a broad general sense to estimate the critical rainfall necessary to cause flooding in adjacent basins should the occasion make it necessary. When the rainfall reports over these basins, within the hydrologic range of the radar, have been averaged, a comparison can be made with the headwater advisory values. Should the radar signal substantiate additional heavy rain falling over the area in question, then a careful surveillance of this area should be maintained using techniques such as discussed in 11.3.3.

A RAWARC or phone alert should be initiated by the radar station to the appropriate RDO regarding designated headwater or flash flood basins whenever:

A. Echoes of the strong or higher category are observed moving toward these basins.

B. Persistent echoes over these areas exceed the STRONG category on the RR/EI chart for 30 minutes or more.

C. Radar indicated rainfall totals exceed 1/2 the amount necessary to cause flooding over that particular river basin.

D. Subsequent echoes to the above indicate rainfall in the moderate or higher category displaying little or no movement over the area of concern.

A rainfall probe should then be considered by the RDO of the suspicious area.

11.4 OTHER APPLICATIONS IN WATER MANAGEMENT

The application of radar for measuring precipitation has steadily increased over the past decade. [6] Radar for this purpose has been succesful through the use of calibrated attenuator circuits in the radar so that the operator obtains intensity readings at selected locations within the storm. These readings, when interpreted on a Radar Rainfall Rate-Echo Intensity graph, provide an estimate of the rainfall rate which is usually accurate within a factor of two. For such applications radar can be an important tool in planning day-to-day or even hourly operations for irrigation districts, hydro-electric plants, conservation reservoirs, flood control structures and for low-flow augmentation.

11.4.1 Hydrometeorology

One of the main uses of radar by the Weather Bureau in hydrometeorology has been the attempt to obtain better coverage and analyses of rain patterns. Studies of intense rains reviewed on radar film are helpful in drawing isohyetal maps and determining how the rains progressed over the area. Radar echoes have also improved identification of moving, non-frontal rain patterns; have shown evidence of "stimulation" of rain by the coast and foothills; and have suggested that orographic rain is usually associated with convergence. [7] In addition, the radar data have been useful in determining windfields in hurricanes through noting locations and intensities of radar echoes.

11.4.2 River Forecasting

One of the requirements of a hydrologist prior to making a river forecast is a rainfall analysis of the storm. The more nearly complete the analysis the better he can prepare an accurate forecast. Radar is used in making this analysis by supplementing the rainfall data collected from the network. This is especially helpful in shower type storms when wide variance in rainfall amounts and areal distribution occurs. Some direct applications are:

A. Operations

1. Early warnings for flood alerts.
2. Activation of community flash flood warning systems.
3. Scheduling of personnel for emergency staffing, stream gaging, flood fighting and relief work.

B. River Forecasting

1. Differentiation between rainfall and snowfall.
2. Detection and location of heavy rainfall in potential flash flood situations including urban storm drainages.
3. Detection of small scale heavy rainfall imbedded in large scale storm systems as potential flash flood producers.
4. Location and intensity of rainfall over reservoir basins.

C. Water Supply Forecasting

1. Detection and location of snowfall.
2. Delineation of snowfall extent.

11.4.2.1 Early Detection Capability

Radar provides around-the-clock precipitation surveillance over large areas from a single point. Heavy precipitation can be detected at any time of the day and night, giving a more complete coverage than is possible with any practical rain gage network. As an example, suppose the intense flood-producing rain occurs between midnight and 6 a.m., observers report the precipitation around 7 a.m. From these rainfall reports, river forecasters would have an indication of the amount of precipitation that fell during the storm even though the time increment of heaviest rainfall was not known. Figure 11-1 illustrates the effect of duration on runoff. A crest produced by a given amount of rainfall would be considerably altered depending upon whether it all fell in a short period of time or was spread over many hours.

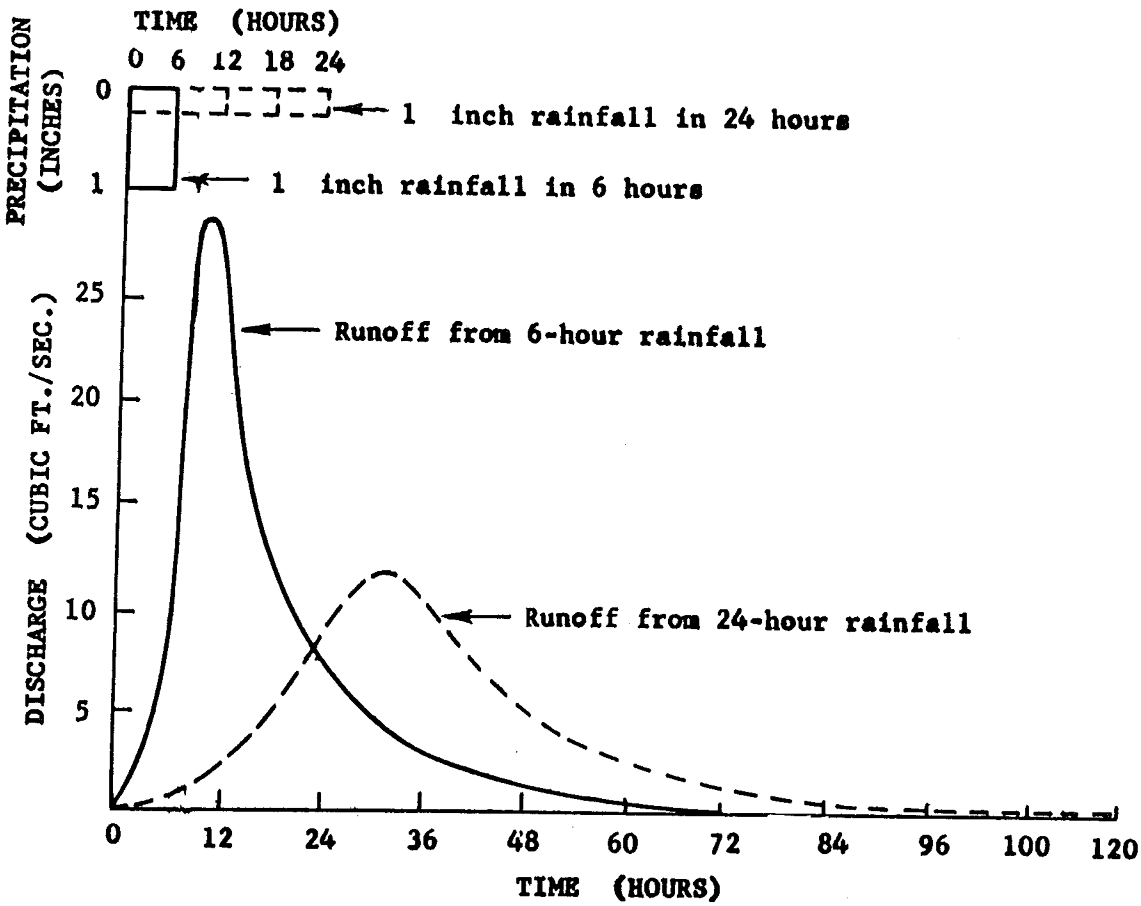


Figure 11-1. Runoff From Storms of Equal Amounts But Different Duration

11.4.2.2 Storm Velocities and Configuration

Careful attention should be given to the velocity and configuration of storm rainfall relative to the orientation and configuration of the catch basin. Where a storm moves over a basin in the direction of flow of the river, we might consider a runoff pattern as indicated in (A) Fig. 11-2. Notice the pronounced peak in streamflow. Suppose, instead the storm now moved upstream, or from east to west in (B) Fig. 11-2. A lower peak flow would result because the rain would be spread over a long time period with respect to the moving river. Consider now the case of a line storm as illustrated in Fig. 11-3. The orientation and velocity of the storm with respect to the basin would be important. If the line were oriented north-south, moving directly east across the basin, the precipitation would begin and end at approximately the same time in the upper and lower reaches of the basin (Fig. 11-3a). An entirely different runoff pattern would be produced if the line were oriented northeast-southwest with movement again in an easterly direction (Fig. 11-3b). In this case precipitation begins in the upper reaches and progresses slowly downstream, thus producing a runoff pattern similar to that of an isolated storm moving downstream as was shown by (A) in Fig. 11-2. Conversely, a northwest-southeast orientation would result in an upstream movement of the storm and a flatter runoff peak (Fig. 11-3c).

The velocity of the line storm, and the angle which the line forms with the basin, determine the speed at which the area of intense precipitation moves over the basin, either upstream or down, and would be reflected in the runoff hydrograph. Rapid storm movement would diminish the duration of precipitation over the basin and, therefore, lessen total rainfall.

11.4.2.3 Observations in Remote Headwater Areas

A radar observation can extend over remote areas where it is practically impossible to establish surface-reporting stations. In mountainous regions especially, there are both fewer people and poorer communication facilities. Many flash floods emanate from such regions where topography adds to the production of heavy rainfall and rapid runoff. Violent flood-producing storms frequently disrupt communications to such an extent that it may be impossible to get reports even from a fairly dense, well-established surface network. It is also feasible to determine the areal extent of storms, especially where there is a network of radar stations. Weather systems that extend over several states can easily be detected. At an individual station small scale features of squall lines can also be readily determined, such as the number and areal coverage of individual flood potential storm cells.

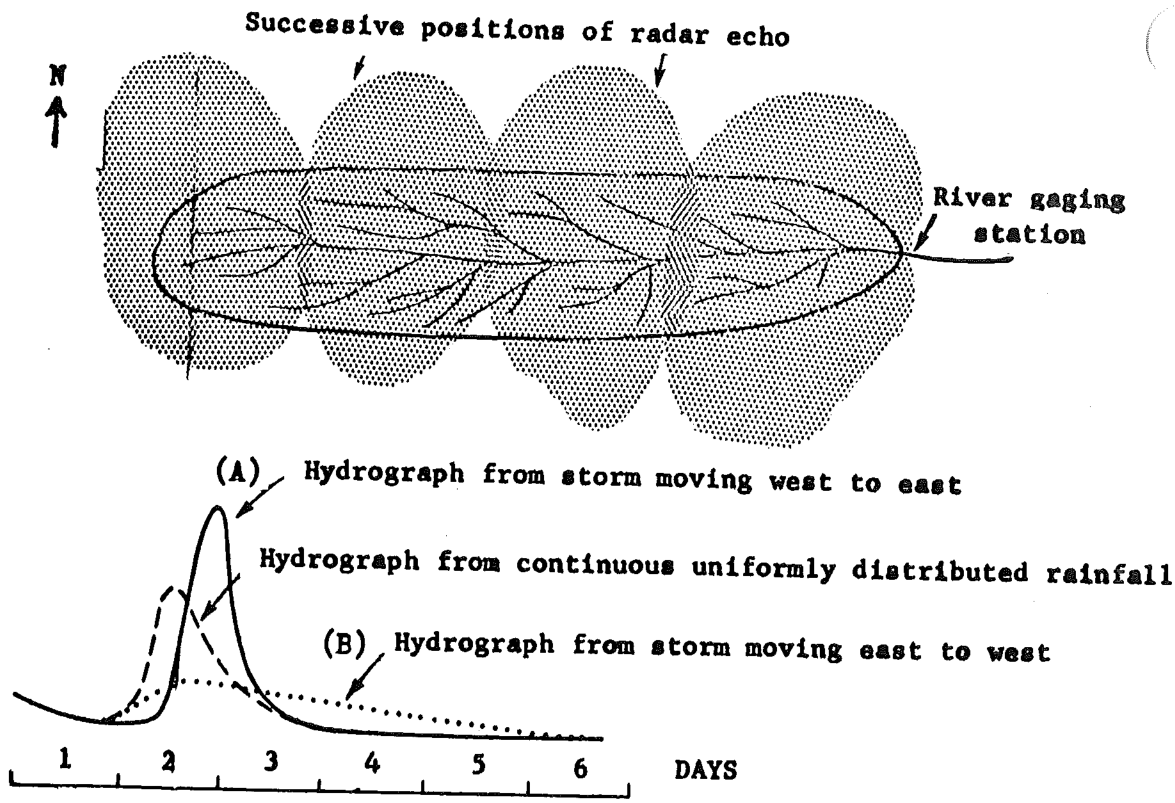


Fig. 11-2 Effect on Runoff Pattern of Storm Movement

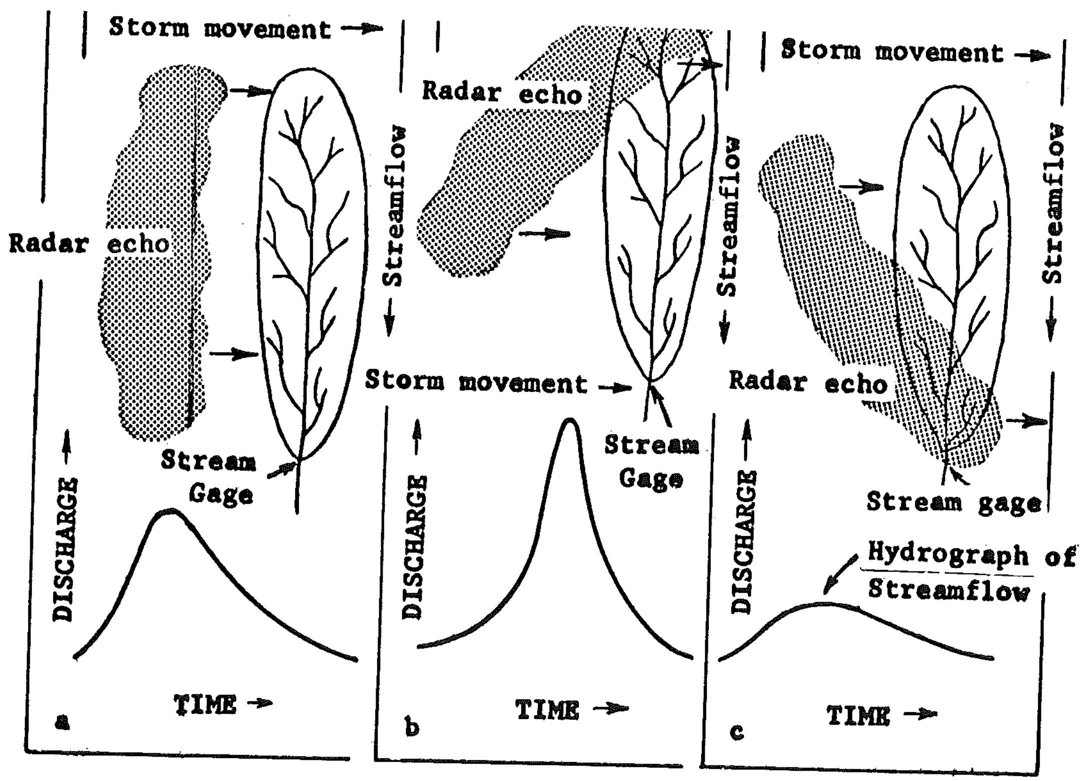


Fig. 11-3 Effect on Runoff Pattern of Orientation and Movement Across a Basin

11.4.2.4 Observations of Precipitation

Storm duration can be ascertained fairly accurately over any portion of a river basin which is within the radar's range. The actual time of beginning and ending of precipitation at any given place within radar range can be determined, usually within an accuracy of a few minutes. Radar can also be useful to the hydrologist for a more comprehensive compilation of antecedent precipitation conditions. This is accomplished in the following manner. Establish a grid system for the radarscope either by arbitrarily-chosen squares or by subdrainage basins within the major river basin. Count the number of hours precipitation was detected in this arbritrarily selected zone, and correlate this figure with the precipitation as determined by rain gage observations. By this procedure, an antecedent precipitation index can be computed for each zone and antecedent conditions can be extrapolated with useful accuracy to areas where rain gage reports are not available. This grid technique has also been applied on a limited operational scale[8] to obtain six-hourly radar estimated values of precipitation. The procedure to obtain precipitation accumulation estimates involves, at 30-minute intervals, contouring predetermined levels of reflectivity. The contours of intensity are initially drawn on the face of the PPI scope in various colors. These outlines are then retraced onto a 100 or 125 n. m. range overlay map which is divided into 10 n. m. grid squares. Successive observations can then be tallied onto a master overlay by use of a light table. Each tally in the grid square can be assigned a rainfall rate value to derive a radar estimated precipitation amount.

To date, radar observations of snow have been primarily confined to the detection of and estimating the areal extent of snowfall. Studies conducted by Haigh and Chapman[a] at Des Moines, Iowa, with a WSR-57 showed that heavy snow could be detected to 100 n. m. but lesser rates could not be readily observed beyond 60 n. m. range.

More recent efforts to estimate rates of snowfall or its water equivalent over extended periods have been successful out to 40 n. m. as reported by Gunn et al.[9] Some success has also been reported by Granger.[8]

(a) WB Progress Report #9 on the WSR-57 Radar Program, 1961.

11.5 AUTOMATION

Broad-scale daily application of radar to measure precipitation cannot be fully realized until an automatic system has been developed to cope with the vast data collection and processing task involved. Manual methods are not capable of doing the job in real time. It is visualized that eventually a network of radars along with computers at control centers will estimate precipitation, make comparisons with surface reports, perform adjustments, and prepare a composited readout in isohyetal, digital or other format.

11.5.1 Meteorological Radar Transponders

General

The MRT system (Fig. 11-4) consists of a tipping bucket activator, Fischer/Porter recording precipitation gage and a transponder shown in Fig. 11-5 that can be interrogated by a signal from the WSR-57 radar. These MRT's[10] are located around selected radar stations and serve to assess rainfall estimated by radar. Accumulated amounts of precipitation appear on the PPI of the interrogating radar in coded form.

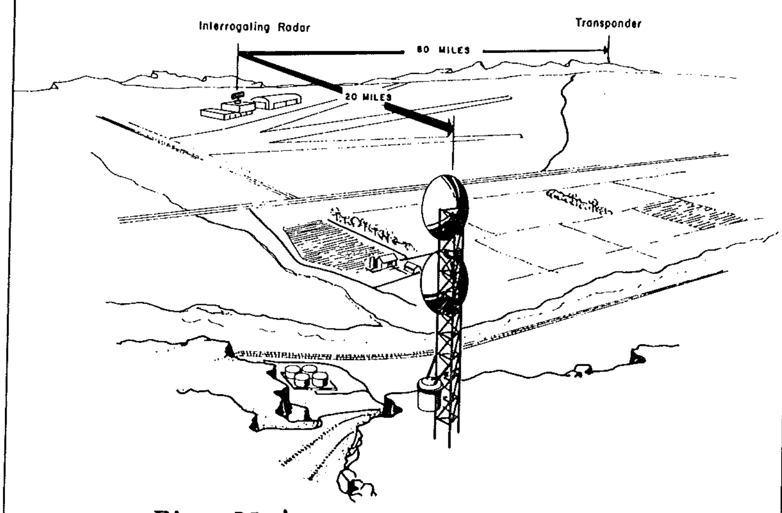
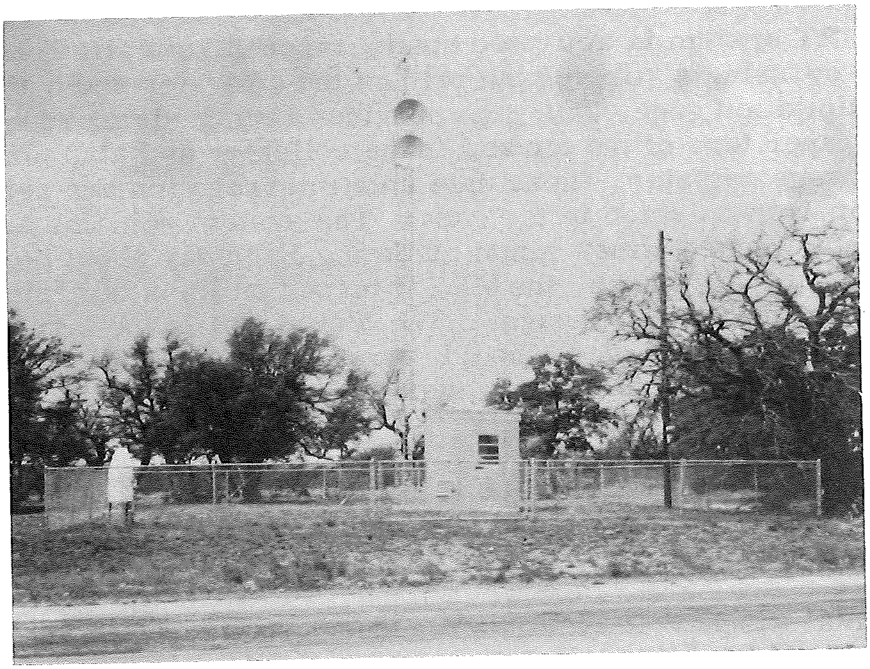


Fig. 11-4 - Typical Location of System Components



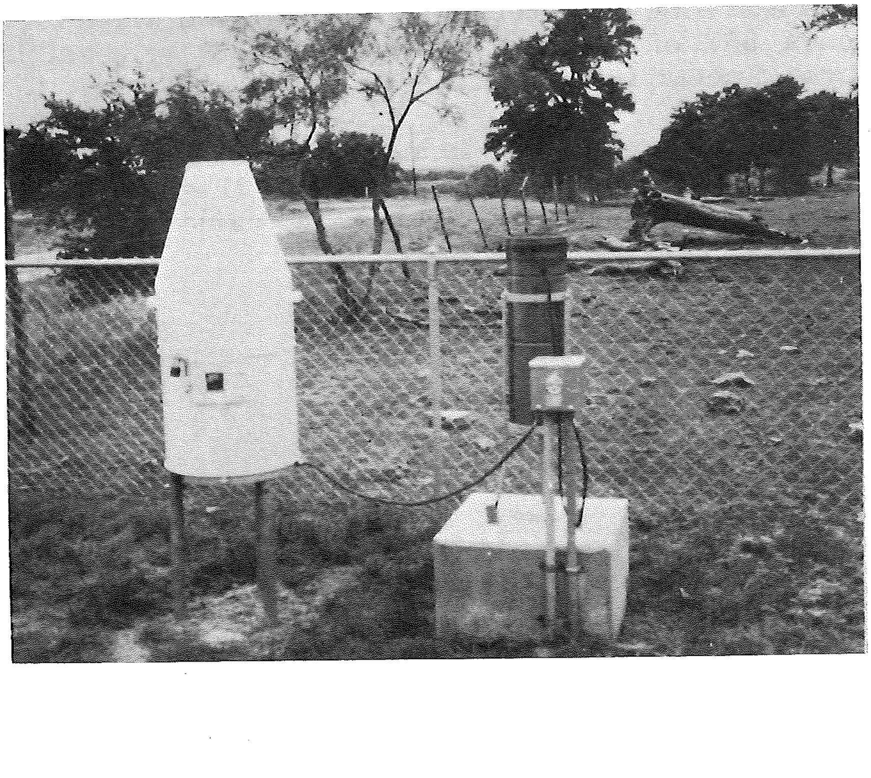


Fig. 11-5 MRT-2 Site with Antenna and Precipitation Gage Placement

11.5.1.1 Operation

The MRT system is activated upon 0.1 inch of rainfall. This is accomplished by using a "tipping bucket" as the activator and a Fischer/Porter precipitation gage. This gage provides a punched record every 15 minutes on paper tape of the amount in the collector and also places the data in a storage register. These data upon interrogation are relayed to the MRT for transmission to the radar. The system remains activated until midnight when a timer shuts it down. Each day about noon, or a time selected by the El Tech, the MRT is turned on for a few minutes by a timer and transmits a test signal. The test signal is the last precipitation amount recorded and should agree with + 0.1 inch of the last amount observed by the monitoring station.

11.5.1.2 Observations

Precipitation is weighed and retained in the 25-inch capacity collector of the Fischer/Porter gage.

The total Fischer/Porter data readout can be 19.5 while the MRT-2 relay logic read is limited to 9.9 inches after which it recycles to zero. It is important that a routine observation schedule, no less than every six hours, be established to maintain proper records. When the MRT recycles the observer takes this into account by adding 10.0 to the next reading. The Field Aide or ElTech should be notified whenever the collector reaches 50% of capacity to avoid overflow or possible loss of record that could occur from a heavy rainfall.

The coded form on the PPI is a series of blips starting at 100 n. m. These blips are on the azimuth of the MRT (Fig. 11-6) and run out in 5 n. m. increments to a maximum of 135 n. m. Values of each blip are:

100 n. m.	0.1	tenths
105	0.2	
110	0.4	
115	0.8	
120	1.0	units
125	2.0	
130	4.0	
135	8.0	

Therefore, if blips were observed at 110 and 130 the gage would be reading 4.4 inches; if blips were observed at 105, 110 and 135 the reading would be 8.6 inches. Since these values are accumulated totals the observer must subtract the previous reading to obtain the incremental

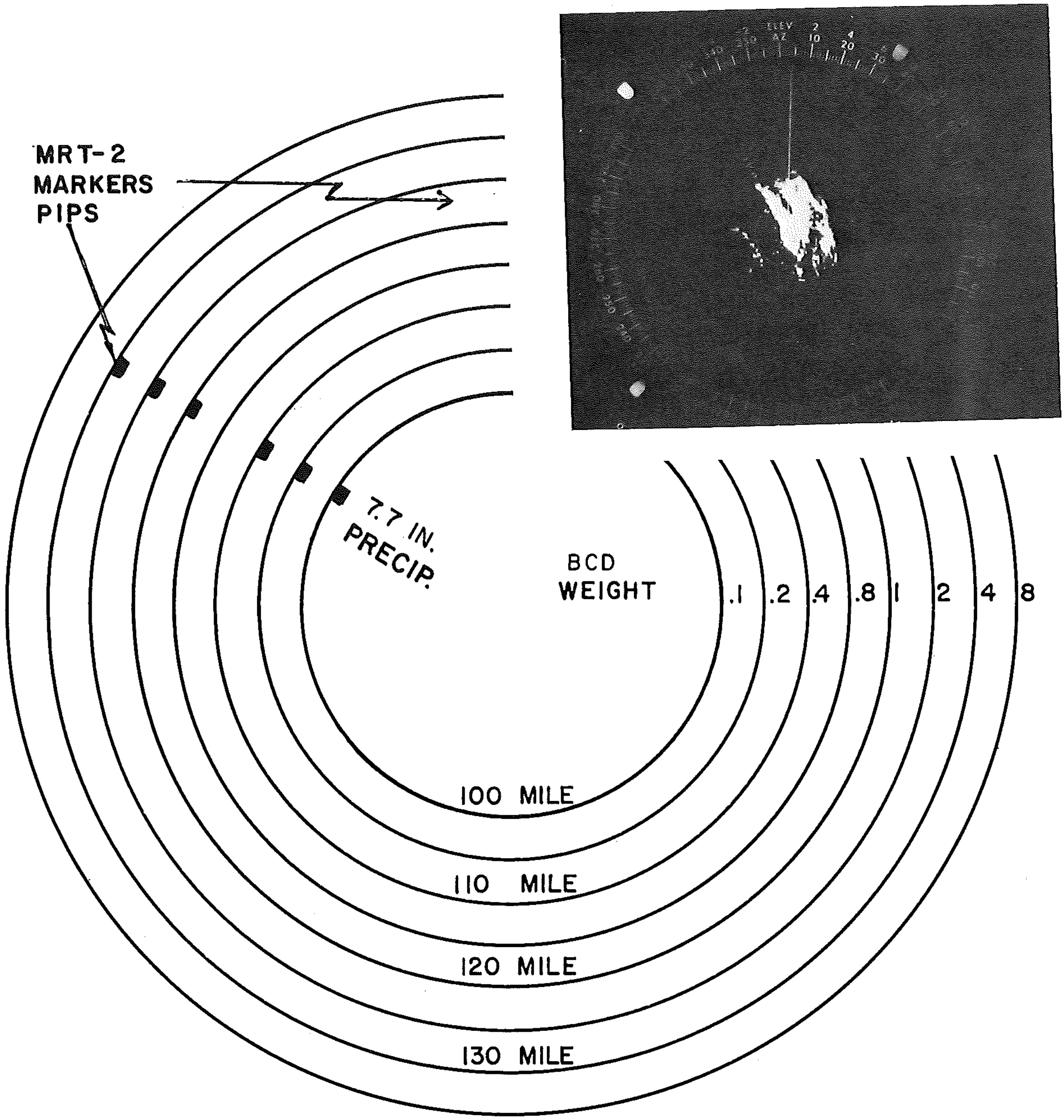


Fig. 11-6 Radar scope

amounts noting the time differences to derive intensity. A 2.0 inch rainfall following 8.6 would be received as 0.6 as the MRT would recycle after 9.9 was reached.

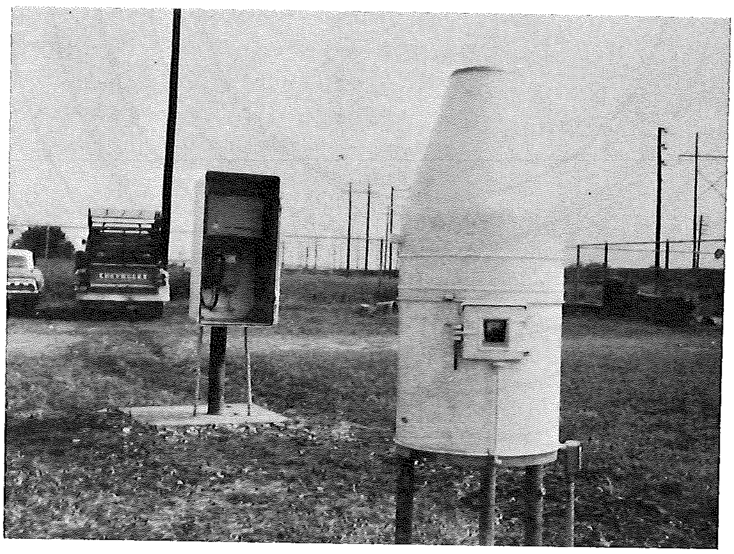
MRT observations should be transmitted at 6-hourly synoptic times to the RDO/RFC concerned and hourly whenever amounts exceed .50 inches per hour.

11.5.2 Telemetering Rain Gages Around Radars

Fischer/Porter telemetering precipitation gages (Fig. 11-7) located around selected radar stations, serve as an index to the areal distribution and intensity of precipitation, and to augment surface reporting networks. These gages are interrogated by telephone.

11.5.2.1 Operations

The Fischer/Porter telemetering precipitation gage has a weighing type precipitation collector with a capacity of 25 inches, however, the



Fisher-Porter Telemetering Rain Gage

tape punchout capability is limited to 19.9 inches. To accommodate snowfall a solution of antifreeze is placed in the collector during the winter season. A small amount of oil is in the collector at all times to retard evaporation. The Fischer/Porter gage punches a record on paper tape every 15 minutes. Upon interrogation the last stored punched data is transmitted.

11.5.2.2 Observations

A reading can be obtained by anyone with access to the telephone number of the gage. Over-interrogation can result in excess drainage on the battery. Selected interrogations, about every six hours, are therefore recommended. However, readings every hour are encouraged during periods of heavy rainfall to help assess radar information and for flash flood detection. These readings are accumulated totals and therefore should be recorded in order to reduce the chance for error.

These observations should be transmitted at 6-hourly synoptic times to the RDO's/RFC's concerned and hourly whenever amounts exceed .50 inches per hour.

11.5.3 Inspection by Field Aide or Electronic Technician

Whenever a Field Aide or El Tech empties or resets the collector in the Fischer/Porter gages at MRT sites or at telemetering rain gage sites the radar station should be notified. Otherwise the radar observer might think the MRT system or gage is not functioning properly. Readouts from the gage should not vary more than 0.1 inch on days without precipitation. Whenever a suspicious reading is noted all efforts to determine its cause should be made before calling the Elec Tech. This can often be done by phoning the property owner where the MRT or gage is located.

11.5.4 Data Processing

The automatic processing and display of weather echo reflectivity values in terms of precipitation is probably the most effective way to handle radar data. This product can take various forms. One useful format for the operational hydrologist with the assigned responsibility of river and flood forecasting is an average rainfall value for preselected drainage basins. This can be accomplished by a properly instrumented and calibrated radar and computer facilities. Investigations along these lines are being conducted by the Weather Bureau.[11]

11.5.4.1 Methodology - Data Recording and Transmission

Recording of the WSR-57 PPI display is facilitated by the reflection plotter, which is standard equipment on the radar. Rainfall echo contours can be quickly traced on the reflection plotter and then retraced onto a reference grid matched in scale by the variable range control. This tracing procedure changes the reference system from polar to rectangular coordinates.

In the NSSL/Ft. Worth RFC Experiment the scale of the rectangular grid reference map was determined by the width of the M-28 teleprinter standard carriage. This simplified TWX transmission. The horizontal grid size is identical to the key spacing and vertical grid size is matched to the line spacing. The grid array is 60 x 36 with a grid element height-to-width ratio of 1.65. When adjusted to a 100 n. m. scope display, grid rectangles are 5.55 x 3.34 n. mi.

By establishing the grid scale to correspond to the teleprinter, the scope tracing can be inserted into the teleprinter (Fig. 11-8). The reflectivity exponent integers, (i.e., 5 for $Z = 10^5$), which correspond to the traced contours, can then be over-punched. The contours are thus "digitized" and ready for computer input. If a computer is colocated with the radar, the teletype conformity need not be adhered to; therefore, any size grid can be selected.

The computer output can yield several displays such as (1) a grid rainfall map (Fig. 11-9) where estimated rainfall amounts are obtained by multiplying radar data by a correction factor, (2) an actual rainfall map conforming to the geography of the area, (3) an average rainfall value for preselected drainage areas, or (4) the end product of a river forecast with no intermediate displays.

In this experiment it was verified for Oklahoma thunderstorms that the moderate to high reflectivity values contribute most of the total area rainfall. Approximately 90% of the area rainfall was contributed by log Z values greater than 3. Thus, the digitization of radar echo data is further facilitated by the narrow range of reflectivity values required to cover the precipitation rate profile. This initial experiment relied on manual digitizing but improvements in techniques and equipment are planned.

Teleprinter Transmission of Radar Digitized Data

Computer Printout of Radar Estimated Rainfall Data

11.6 REFERENCES

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Chapter 12

CLIMATOLOGICAL PROCEDURES

12.1 INTRODUCTION

Climatological analyses applied to radar weather observations may offer exceedingly interesting and valuable information. As a little reflection will reveal, radar observations have a great deal to contribute to this aspect of meteorology.

Most processing of meteorological data is conducted at central collecting centers where high speed computers quickly and efficiently reduce large quantities of observational data into useful climatological information. Unfortunately, radar data are not immediately available for machine processing since they are not recorded in a digital form and therefore cannot be placed directly on punch cards. Techniques that will produce radar data in the proper form are currently in the research and development stage. One method for digitizing radar data is discussed in ¶12.3.

Radar, being a relatively new meteorological instrument, is not presently being used as a routine source for comprehensive climatological studies; however, radar does have a potential for such use. At the present, radar records consist of (a) entries on Form 60, "Radar Weather Observations", (b) time-lapse photography of the PPI scope, and (c) Polaroid photographs. The time-lapse records are the most useful since they are the most reliable means of automatically transcribing data at frequent intervals from the PPI scope to a permanent form.

To compile a suitable radarscope film record for climatological purposes both radar and time-lapse camera must be functioning when precipitation echoes are within range to assure a continuous record. Five years are usually considered the minimum period necessary to determine seasonal, diurnal or geographical variations of common meteorological values such as temperature, wind, cloud cover, visibility, and precipitation. In most cases an equal period of record probably is required for radarscope data. There are, of course, exceptions and some information of climatological significance may be determined in less time. Moreover, the quality of the films must be high enough so that it always presents an accurate representation of the PPI display and the equally important auxillary information such as date-time data, recorded with each frame of film (see Chapter 10, Radarscope Photography).

12.1.1 Radar Data of Climatological Significance

Although radar data are not yet being utilized as a routine source for comprehensive climatological studies, it is readily apparent that radar weather observations are capable of providing the following climatological information:

(1) Occurrence or non-occurrence of precipitation echoes over inaccessible regions such as mountains and water areas.

A rain gage network records the presence of rain at specific points, while the radar detects the areal distribution of precipitation. However, range resolution, beam width inaccuracies, and height of the beam above ground complicate the problem at ranges greater than 100 miles.

(2) Estimation of seasonal variations of rainfall intensity on radars equipped with proper calibration equipment.

(3) Frequency of occurrence of precipitation echoes over specific regions as a function of hourly, monthly or seasonal variations and differing synoptic situations.

(4) Location of favored regions for echo development.

(5) Effect of terrain features on orographic precipitation during different synoptic situations.

12.2 GRID OVERLAY

A simple method for obtaining basic data for climatological studies is through use of a grid overlay. The overlay may be placed over the PPI scope at prescribed intervals and echo occurrences recorded. To be of greatest significance, squares should be small enough to produce more detail than available from existing rain gage networks, yet not so small as to create an extremely laborious data reduction procedure. Optimum size of the grid squares would be 15 nautical miles for each side of the square. For climatological procedures, river basin boundaries and rain gage locations are probably not required.

A tracing paper overlay cannot be used on the WSR-57 radars because the reflection plotter keeps the overlay too far away from the scope. When viewed through the tracing paper the echoes appear blurred and indistinct. This problem may be overcome by first outlining the echoes and the maximum range marker on the reflection plotter and then tracing on the paper overlay from the reflection plotter. Another method would be to construct a grid on an acetate or clear plastic sheet with india ink and marked in grease pencil. A transparent grid overlay is also available on request from the DATAC Division in the Central Headquarters. These grids have 15 mile squares and are for use on the 250, 200, and 125 nautical mile ranges of the WSR-57 radar. Direct tracing through this overlay is easily accomplished. Projected film images may be analyzed in a similar manner.

After each storm situation has gone beyond the range of the radar, and the PPI is clear of precipitation echoes, radar personnel can devote time to tabulating the number of grid squares occupied with precipitation echoes during the past storm and the frequency that echoes were detected (number of tick marks accumulated) in each square. During the summer season radar surveillance of air-mass shower activity may provide a great deal of information with regard to favored areas of development as revealed by daily recording of echo occurrences on a grid overlay.

12.3 RECORDING OF DATA

In order to process radarscope time-lapse data in a manner similar to that used with other kinds of meteorological data the PPI display must be "digitized". This can be accomplished with the grid system discussed in ¶12.2.

Each square of the grid is identified by four digits representing the column-row coordinates of the square; two digits specify the grid column occupied by the square, and two specify the grid row.

The PPI display at a given time can be reduced to a list of grid squares which contain precipitation echoes. If no precipitation were observed then no grid squares would be listed.

With the square's numbers tabulated on punched cards, the radar data may be processed with regard to echo location, persistence and areal distribution. In addition, data on rainfall intensity may be included on the punch card if receiver attenuation values are included on the PPI film record, as they are with the WSR-57. With radar data transferred to punched cards, machine processing presents new opportunities to investigate precipitation phenomena. For example, it would be relatively easy to determine the percent of a region within range of a radar covered by precipitation echoes during different synoptic situations, and the variations of these percentages by season. Variations of areal coverage could be investigated with regard to diurnal change. Late afternoon might be a favored time for the development of precipitation in one region, while nocturnal showers might be an important factor in the climatology of another section.

Terrain features may influence the distribution of precipitation over a region more than is suspected. Rain gage measurements, upon which our present climatology of precipitation is based, all too often represent only the amount received on flat easily accessible locations while the inaccessible areas tend to negate the collection and plotting of data from these areas. Any orographic precipitation would most likely fall in these locations and probably be unmeasured by the rain gage network. Radar will detect such precipitation and provide an estimate of the amount of rain reaching the ground, and persistence of the echoes may reveal the terrain feature responsible for the lifting.

The distribution of precipitation over large bodies of water, such as the Great Lakes, is an interesting problem which offers an opportunity for utilizing weather radar data. Land-water variations of the areal distribution of precipitation with different synoptic situations, seasons, or diurnally may become apparent by noting the frequency of occurrences of precipitation echoes on the PPI scope. Here again, the grid overlay combined with punched cards and machine processing makes possible the reduction of the large amounts of radarscope data necessary to determine the climatology of important lakes or costal areas. Since radar is the only means to measure precipitation within these regions, it should be utilized fully to record all types of precipitation under all synoptic situations. Station personnel can initiate their own studies along this line by employing the grid overlay technique and keeping a running tally of echo occurrences in the grid squares representing the atmosphere over the land and water surfaces. This operation must be continuous to be effective, which means that radar observers on all shifts must routinely mark the grid overlay as long as precipitation echoes are within range of their radar, in addition to performing their other duties. For an effective climatological study, the data must be as continuous and accurate as possible. To supply useful climatological data, the radar must operate during all situations when precipitation is within its range and must produce an accurate record. Without these last two conditions being met, it is doubtful whether any useful climatological studies could be conducted.

APPENDIX

GLOSSARY

angels - Radar echoes not directly visible to the eye. They have been ascribed to birds, insects and refractive index discontinuities.

attenuation - The reduction in the power of the transmitted signal due to scattering or absorption of energy by atmospheric gases, clouds and precipitation. It may also refer to the decrease of power in a beam with increasing distance from the radar.

beam width - The angle in degrees subtended at points across the axis of the beam where the power density is one half that at the beam axis.

bright band - The enhanced radar echo of snow as it melts to rain, as displayed on a range-height indicator (RHI).

calibration - The process whereby a position on the scale of an instrument is identified with the magnitude of the signal actuating that instrument.

cathode ray tube - A vacuum tube consisting essentially of an electron gun that produces a concentrated electron beam (or cathode ray) that impinges on a phosphorescent coating on the back of a viewing face (or screen). The excitation of the phosphor produces light, the intensity of which is controlled by regulating the flow of electrons. Deflection of the beam is achieved either electromagnetically by currents in coils around the tube, or electrostatically by voltages on internal deflection plates.

coherent radar - A radar, such as pulse Doppler, in which the phases of the transmitted radiation is preserved for comparison with that of the incoming signal.

coherent echo - A radar echo whose phase and amplitude at a given range remain relatively constant.

convective precipitation - Precipitation from convective (cumuliform) clouds.

dark trace tube - A cathode ray tube which permits storage of radar information for an indefinite period. The information is retained as a dark (magenta) image on a white background until erased by applying heat from a filament behind the display area.

dielectric constant - For a given substance, the ratio of the capacity of a condenser with that substance as a dielectric to the capacity of the same condenser with a vacuum as a dielectric.

Doppler effect (or shift) - A shift in frequency caused by a target with relative motion away from or toward the radar.

duct - A rather shallow, almost horizontal layer in the atmosphere through which vertical temperature and moisture gradients are such as to trap the radiating energy enabling the radar to detect targets at abnormally long ranges.

duty cycle - The ratio of the average power output to the peak power output of the radar.

dynamic range - As applied to CRTs, intensity modulated, i.e., PPI tubes, is the range from a minimum visually displayed signal to a visually saturated displayed signal.

gain - (a) Antenna gain is the ratio of the power transmitted along the beam axis to that of an isotropic radiator transmitting the same total power.

(b) Receiver gain is the amplification given a signal by the receiver.

index of refraction - A measure of the amount of refraction in a given medium. It is the ratio of the wavelength or phase velocity of an electromagnetic wave in a vacuum to that in the medium.

LEWP - Line Echo Wave Pattern.

lobe - A beam of focused radio energy defining a surface of equal power density. The major lobe is at the beam axis. Side lobes, which contain much less energy than the major lobe, are displaced at appreciable angles from the axis of the beam.

logarithmic receiver - A receiver in which the power output is on a logarithmic scale thus preventing signal saturation.

mesoscale - A scale smaller than the cyclone or macroscale and larger than that of the immediate environment or microscale. Tornadoes and thunderstorms are mesoscale phenomena. The scale observable by radar is essentially mesoscale.

microwave radiation - Electromagnetic radiation covering the wavelength range from about 100 to 0.01 cm.

minimum detectable signal - A received signal whose power is just above the noise level of the receiver.

modulation - In radio, a process whereby the characteristics of a radio carrier-wave are modified by a second, or modulating wave. A carrier-wave (of constant radio frequency) must be modulated in order to carry information.

noise - Any unwanted, usually random, fluctuation of a signal.

noise figure - Ratio of the noise generated by an actual receiver to the theoretical (thermal) noise of an ideal receiver.

normalization - A modification of receiver gain function whereby echo target intensities are compensated for r^2 attenuation.

polarization - The state of electromagnetic radiation when transverse vibrations take place in some regular manner, e.g., all in one plane, in a circle, in an ellipse.

pulse integrator - An electronic device for the measurement of the average received power from a target illuminated by a pulsed transmission.

pulse length - (Also called pulse width) The linear distance occupied by a pulse of transmitted radio energy in space. The length h of such a pulse in centimeters is equal to ct, c being the speed of light and t being the time interval between the beginning and end of the pulse transmission (the pulse duration).

pulse repetition frequency - (Abbreviated PRF; also called pulse recurrence frequency) The frequency with which pulses of radio energy are transmitted by a pulse radar. The PRF determines the range of pulse radars, the lower the PRF, the greater the range.

reflectivity - The equivalent area of an isotropic scatterer which scatters energy in all directions equal to that scattered directly back to the radar by the target.

reflectivity factor - The summation $Z = ND^6$ where N is the number of particles with equivalent drop diameter D.

refraction - The process in which the direction of energy propagation is changed as the result of a change in density within the propagating medium, or as the energy passes through the interface representing a density discontinuity between two media. In the first instance the rays undergo a smooth bending over a finite distance. In the second case the index of refraction changes through an interfacial layer that is thin compared to the wavelength of the radiation; thus, the refraction is abrupt, essentially discontinuous.

scattering - The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions. Scattering varies as a function of the ratio of the particle diameter to the wavelength of the radiation. When this ratio is less than about one-tenth, Rayleigh scattering occurs in which the scattering coefficient varies inversely as the fourth power of the wavelength. At larger values of the ratio of particle diameter to wavelength, the scattering varies in a complex fashion described by the Mie theory; at a ratio of the order of ten, the laws of geometric optics begin to apply.

sensitivity time control (STC) - Provides a modification of receiver gain function which may or may not provide range normalization.

signal generator - An electronic instrument used for the production of simulated electric (or radio) signals with certain desired characteristics. It is useful in testing and calibration.

stratiform precipitation - Precipitation from stratiform or layer clouds.

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Weather Radar Manual

PART C

OCTOBER 1973

SECTION I
INSTRUCTIONS FOR MAINTAINING
PART C WEATHER RADAR MANUAL

SECTION I

INSTRUCTIONS FOR MAINTAINING PART C OF THE WEATHER RADAR MANUAL

WSH ISSUE NUMBER	TITLE	DATE
1-WSH	INSTRUCTIONS FOR MAINTAINING PART C OF THE WEATHER RADAR MANUAL	10/73

SECTION I

INSTRUCTIONS FOR MAINTAINING PART C OF THE WEATHER RADAR MANUAL

RH ISSUE NUMBER	TITLE	DATE

FILE WITH SECTION I, INSTRUCTIONS FOR MAINTAINING PART C, WRM

INSTRUCTIONS FOR MAINTAINING PART C OF THE WEATHER RADAR MANUAL

Description of the Weather Radar Manual. The Weather Radar Manual (WRM) contains instructions and other material necessary to the operation of radars assigned to the National Synoptic Weather Radar Network (RADARNET). The manual was developed and assembled by a working group under the Sub-Committee on Basic Meteorological Services of the Interdepartmental Committee for Meteorological Services (SC/BMS-ICMS). The observing and reporting instructions found in Part A of the manual must be followed by anyone reporting on RADARNET. Part B provides a convenient general introduction to the principles and uses of weather radar along with techniques for interpreting, processing, and displaying weather data. Any changes or additions made to these two parts of the manual must be agreed upon by SC/BMS-ICMS (working group).

Part C of the WRM provides these instructions and other material necessary to the operation of specific programs and equipment that are not contained in Parts A or B. Part C instructions and material may be issued by individual agencies or offices as required to pursue their own operations, and therefore the form and content of Part C may vary from agency to agency, and even from office to office.

The National Weather Service Part C.

Authority. The National Weather Service Part C, WRM, will have certain material, issued by Weather Service Headquarters (WSH) common to all copies of the manual. Other material, issued by the Regional Headquarters (RH) will be common to entire regions or particular offices as designated. Radar operating instructions originating at any office for local use should also be included in Part C. Unless specifically authorized, instructions and information issued by the regions shall not conflict with, or supersede, that issued by WSH, and issues by individual offices shall not conflict with, or supersede, issues by either the Weather Service Headquarters (WSH) or the Regional Headquarters (RH).

A copy of any authorization for deviation from this policy shall be filed in the manual along with the pertinent instructions. Each office that issues Part C material will designate a control point for the coordination of all issuances from that office. At WSH, the control point is the Chief, Radar Meteorology Staff, W143x1, DATAC. A copy of every regional issuance shall be sent to him. Each office that operates a radar will maintain a Weather Radar Manual, including Part C, and regional offices will maintain copies of all issuances applicable in their respective regions. Each issuance will contain a distribution list that may not specifically include the Regional Headquarters or WSH. These offices will nonetheless receive a copy of all issuances.

Content. The National Weather Service Part C will include those instructions and materials, not contained in Parts A and B, necessary for the proper use of radars and auxiliary equipment for the pursuit of programs for observing and analyzing weather with radars, and for disseminating radar information. Much of the material may be part or all of other publications, entered into Part C with a cover page. Those parts of station duty manuals that pertain to radar operations will be included in Part C. Detailed instructions to Electronics Technicians for repair and maintenance of equipment will not be included, although certain calibration procedures and certain policy matters published elsewhere may be included for easy access by Weather Radar Specialists. Chapter B-50 of the NWS Operations Manual will be included for the same reason. OML's and ROML's pertaining to radar or related matters should also be included. All material designated as part of Part C will be placed in a binder with the rest of Part C, even though copies may be available in other publications. In case the material is too bulky for inclusion in the Part C binder or is not separately available, the issuance cover page will be placed in the binder. This cover page should clearly designate the material to be included and where it can be found.

Form. Each issuance will be numbered serially by the issuing office, with a serial number including the office identification. Example: This instruction is found in Issue Number 1, WSH, as shown on the heading of the first page of the issue; the first issue from Eastern Region Headquarters will be Issue Number 1, ERH; and the first issue by Tampa WSO will be Issue Number 1, TPA. Each issuance will include only one set of instructions or material on only one subject.

The heading of each issue will have the same form as that found on page 1 of this issue. Note the spacing, and that the title of the issue is centered and capitalized. If an issue has more than one page, each page will be numbered, provided the page originates with the issue. It is not necessary to renumber pages of other publications being entered as part of Part C. The pages will be identified as in this issue: the number in the upper left corner of even numbered pages, and in the upper right corner of odd numbered pages. The title of the issue, or a contraction of the title, will appear on the same line as the page number.

Whenever an issue consists of identifying another publication for inclusion in Part C, a cover page will be prepared with the standard heading and full instructions. The cover page will be placed in the manual binder, and a copy of the publication will also be placed in the binder, if feasible. Any material identified as part of Part C must be available at the concerned radar sites, and if not in the binder the issue cover page must identify its location.

Part C will be divided into various sections as shown below. Each issue will be placed in one of these sections, depending on its applicability. Each section will be headed by a listing of the issues in the section, title, and date of each. Whenever an issue is superseded or voided, the issue will be removed from the binder and an appropriate note, with date, made on the list of issues. The sections are as follows:

SECTION I, INSTRUCTIONS FOR MAINTAINING PART C OF THE WEATHER RADAR MANUAL

SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

SECTION IV, RADAR REPORTS

SECTION V, RADARSCOPE PHOTOGRAPHY

SECTION VI, LOCAL INSTRUCTIONS

SECTION II
FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

SECTION II

FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

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1-WSH	ORIENTATION OF THE ANTENNA	10/73
2-WSH	GROUND CLUTTER PHOTOGRAPHS	10/73
3-WSH	EQUIPMENT INSTALLATION, ACTIVATION AND COMMISSIONING	10/73
4-WSH	RADAR MAINTENANCE DURING PERIODS OF SIGNIFICANT WEATHER	10/73
5-WSH	OPERATING INSTRUCTIONS FOR WSR-57 RADARS	10/73
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7-WSH	WSR-1 RADAR OPERATING INSTRUCTIONS	10/73
8-WSH	OPERATING INSTRUCTIONS FOR WSR-1A, WSR-3 AND WSR-4 RADARS	10/73
9-WSH	OPERATIONAL PROCEDURES FOR ARTC TYPE RADAR	10/73
10-WSH	AIR ROUTE TRAFFIC CONTROL RADARS	10/73
11-WSH	OPERATING INSTRUCTIONS FOR VE-1 REPEATER	10/73
12-WSH	OPERATING INSTRUCTIONS FOR VD-2 REPEATER	10/73
13-WSH	OPERATION OF ALDEN CONTINUOUS FLAT COPY SCANNER	10/73
14-WSH	RADAR HAZARDS	10/73

SECTION II

FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

RH ISSUE NUMBER	TITLE	DATE

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

ORIENTATION OF THE ANTENNA

Antennas for radar sets installed at Weather Service Stations will be oriented with respect to true north. True north for the radar site will be determined as prescribed in FMH No. 5.

If possible, establish true north for the radar site before placing the antenna on its platform.

Establish the azimuth bearings and the distances from the radar antenna for a number of prominent objects around the radar site. The points selected should be easily identifiable in the ground clutter so that they will be suitable for checking the orientation of the antenna and the range indication of the radar set. A photograph of the ground clutter, such as a Polaroid print, mounted on the console or filed in the station Weather Radar Manual will be useful in identifying check points.

Note that the FAA and Air Defense Command radars are oriented with respect to magnetic north. Data should be corrected for true north before transmission on teletypewriter circuits.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

GROUND CLUTTER PHOTOGRAPHS

In order to provide and maintain a reference set of photographs, the following procedure should be carried out within 30 days after a radar is installed or relocated, or when new construction causes a change in the obstruction pattern.

1. Select Standard Conditions. Normal propagation (indicated by average extent of ground clutter), no precipitation within 50 miles, and no unusual interference.

2. Set Radar Controls. Standard gain, long pulse, STC and VIP off, 50-mile range, all radarscope controls at optimum settings.

3. Obtain Exposure. Set time lapse camera for one exposure every other scan; use optimum aperture (usually f5.6 or f8) and optimum adjustment of radarscope and data chamber lighting. Obtain three consecutive exposures.

4. Identify Photographs. Note date, time, and frame numbers.

Notify the Data Acquisition Division (W143) by memorandum when these photographs have been made. Send one copy of this memorandum to the Regional Headquarters and one to the NCC D5213 (5590). Attach the latter copy to the film can at the time the film is forwarded for processing. Include in the memorandum the information specified in item 4., above, and a description of the ground clutter pattern.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

EQUIPMENT INSTALLATION, ACTIVATION AND COMMISSIONING

See Weather Service Operations Manual, chapter A-34, paragraphs 2.7 and 2.11 through 2.11.6.

This cover page should be placed in Part C, Section I of the Weather Radar Manual. Its purpose is to indicate that chapter A-34, paragraphs 2.7, and 2.11 through 2.11.6 of the NWS Operations Manual should be considered a part of Part C, WRM.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

RADAR MAINTENANCE DURING PERIODS OF SIGNIFICANT WEATHER

I. INTRODUCTION

This is to define guidelines to be used in determining when the NWS radars should receive scheduled preventive maintenance, calibration checks, and corrective maintenance. Nearly all radar stations now operate within these guidelines, and it is not expected that significant changes in procedures will be necessitated by these instructions. These guidelines are designed to insure the best radar coverage at the most critical times. However, in exceptional cases it may be necessary to vary the method to achieve the best result. The decision to deactivate the radar for maintenance or alignment purposes, or to require unscheduled work periods, rests with the Meteorologist in Charge of the radar station, or in his absence, with the concerned Weather Service Forecast Office.

II. ROUTINE MAINTENANCE AND CALIBRATION CHECKS

A preventative maintenance and calibration check routine should be established, but it must be flexible to allow the radar to be used to the best advantage. Routine maintenance and calibration checks should not be performed if:

1. Severe Weather or Hurricane Associated Echoes

   a. Exist over area of surveillance.

   b. Are forecast to exist over the area of surveillance before the radar can be restored to service.

2. Echoes of Strong or Greater Intensity

   a. Exist within 125 miles of the radar.

   b. Are forecast to exist within 125 miles of the radar before the radar can be restored to service.

3. Echoes Over a Large Part of the PPI

   a. Exist.

   b. Are forecast to exist before the radar can be restored to service.

4. Flooding Exists in the Area of Surveillance, and Rainfall

   a. Is occurring.

   b. Is forecast to occur before the radar can be restored to service.

5. The Meteorologist in Charge of the radar station determines that because of an unusual situation the public interests could better be served by continued operation of the radar. Sensitive crop harvests, forest fire hazards, and other such considerations may render radar weather coverage exceptionally useful on particular days even in the absence of severe weather, and our program should be sufficiently flexible to accommodate whenever possible. Special coverage for large public gatherings, election days, and so forth, will have a salutory effect even if the weather is good. Such considerations should not overshadow the primary mission of the radar, however, and it is not intended that routine maintenance or calibration checks be delayed if it appears they might not then be performed before the onset of bad weather. The Meteorologist in Charge may be guided in his decision by consultation with the Weather Service Forecast Office.

III. CORRECTIVE MAINTENANCE

In case accurate PPI display is impossible, immediate remedial action should be taken if an electronics technician is on duty, and if no extraordinary hazards to personnel safety exist. If an electronics technician is not on duty the Meteorologist in Charge may, if weather conditions warrant, authorize unscheduled work and require the presence of a technician to repair the radar. The Weather Service Forecast Office may also require that the radar be repaired and will assume the responsibility for the decision whenever the station MIC is not on duty. If the MIC or the Weather Service Forecast Office do not think conditions warrant the immediate repair of the radar, repair may be delayed until the next scheduled work period of the electronics technician. In making the decision, the radar station's network responsibility and the amount of time to elapse before the next scheduled work period of an electronics technician should be considered, along with the anticipated weather.

It is the responsibility of the radar observer to immediately notify the MIC or the Weather Service Forecast Office when the radar becomes inoperative, and to notify an electronics technician of necessary action, if directed to do so.

In case accurate PPI display is possible but some other component is not functioning properly, or the radar is operating below established standards, repairs will be made immediately if an electronics technician is available and if the repair can be made without taking the radar out of service (the radar can be considered "in service" if it is radiating and rotating or is ready to radiate and rotate). If it is necessary to take the radar out of service to effect the repairs, the radar observer should first determine that none of the criteria of paragraph II are satisfied. If precipitation is forecast during the anticipated outage time, the MIC or the Weather Service Forecast Office should be consulted before the repairs are attempted. Such repairs will ordinarily be made during scheduled electronics technician work periods.

IV. SPECIAL EFFORTS

Occasions may arise when a special effort is indicated in order to bring the radar to highest effectiveness because of anticipated severe weather or hurricanes. For instance, unscheduled calibration checks may be required by the MIC during the distant approach of a hurricane, and unscheduled work by electronics technicians may be required by the MIC or the Weather Service Forecast Office in order that the radar will operate at its full capability during periods of significant weather. It is the responsibility of the radar observer to determine, by his own checks and by discussion with the electronics technician, that the radar is at top effectiveness, and to recommend to the MIC any actions he thinks necessary.

V. REFERENCES

Pertinent instructions may be found in the NWS Operations Manual, at the following places:

Chapter C-40, 8.1.4.a, 8.3.11, and 9.

Chapter C-41, 6.1.d, 6.2, and 6.3.

Chapter H-50, 5.1 and 5.3.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

OPERATING INSTRUCTIONS FOR WSR-57 RADARS

General. The WSR-57 Radar is an S-band system, specifically designed for meteorological use. It has a maximum range of 250 nmi and operates at a frequency of 2,700 to 2,900 mc, which corresponds to the wavelengths of 11.1 to 10.3 cm, respectively. Nominal peak power is 500 kW.

Operating Controls and Their Functions. All the operating controls for the WSR-57 are located on the Console (fig. 1), distributed among six panels. These are, from left to right, and from top to bottom; the A/R Indicator Panel, the Power Panel, the Plan Position Indicator Panel, the Attenuator Panel, the Range-Height Indicator Panel, and the Fuse Panel.

The A/R Indicator Panel (fig. 2).

(1) DIMMER — Controls the illumination of the digital range dial (7). In the extreme CCW position, turns illumination OFF.

(2) ASTIGMATISM — Vertical focus control for the sharpest presentation of the image on the A/R scope. Used in conjunction with (4).

(3) INTENSITY — Controls the brilliance of the sweep on the A/R scope.

(4) FOCUS — Horizontal focus control for the sharpest presentation of the image on the A/R scope. Used in conjunction with (2).

(5) RANGE MARK AMPLITUDE — Controls the amplitude of the range marks on the A/R scope. In the extreme CCW position, turns the range marks off.

(6)	VIDEO AMPLITUDE	Controls the video gain and, therefore, amplitude of the display on the A/R scope.
(7)	MILES	Digital dial controlled by the Range Strobe (8) which indicates the range to a target in nautical miles.
(8)	RANGE STROBE	Handwheel that controls the position of the range strobe on the A-scope.
(9)	STROBE AMPLITUDE	Controls the amplitude of the strobe on the A-scope. In the extreme CCW position, turns the strobe off.
(10)	PEDESTAL AMPLITUDE	Controls the amplitude of the pedestal above the sweep on the A-scope. In the extreme CCW position, turns the pedestal off.
(11)	SWEEP SELECTOR	Switch to select the type of display, either A-scope or R-scope.
(12)	R-SWEEP RANGE-MILES	Control to select the magnitude of the display on the R-scope from 5 to 25 nautical miles. This corresponds to the length of the A-scope pedestal which is also adjusted by this control.
(13)	A-SWEEP RANGE-MILES	Four-position switch to select the range displayed on the A-scope. The ranges are 25, 50, 125, or 250 nautical miles. 250 is used only on long pulse.

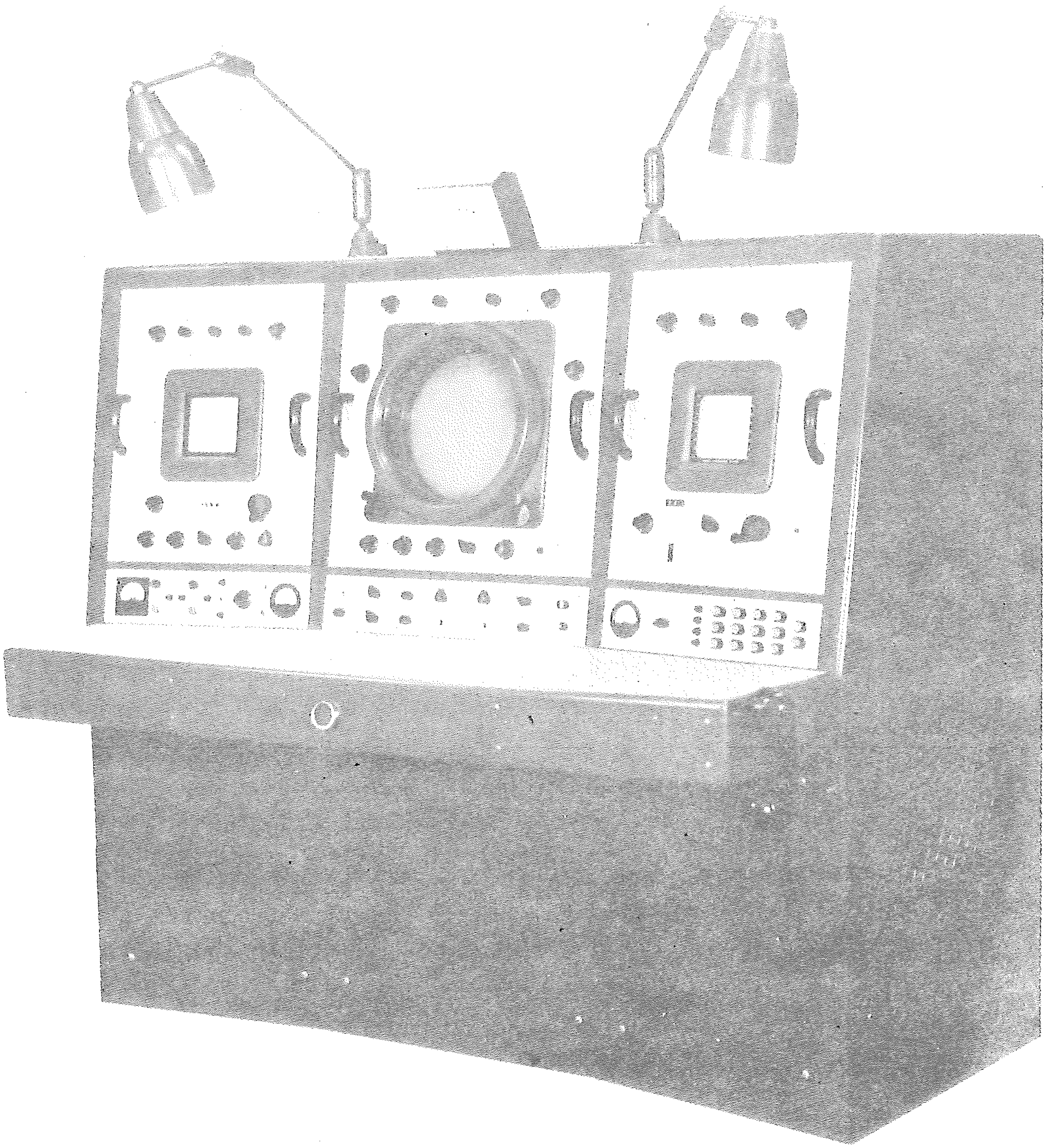

Figure 1. WSR-57 Console

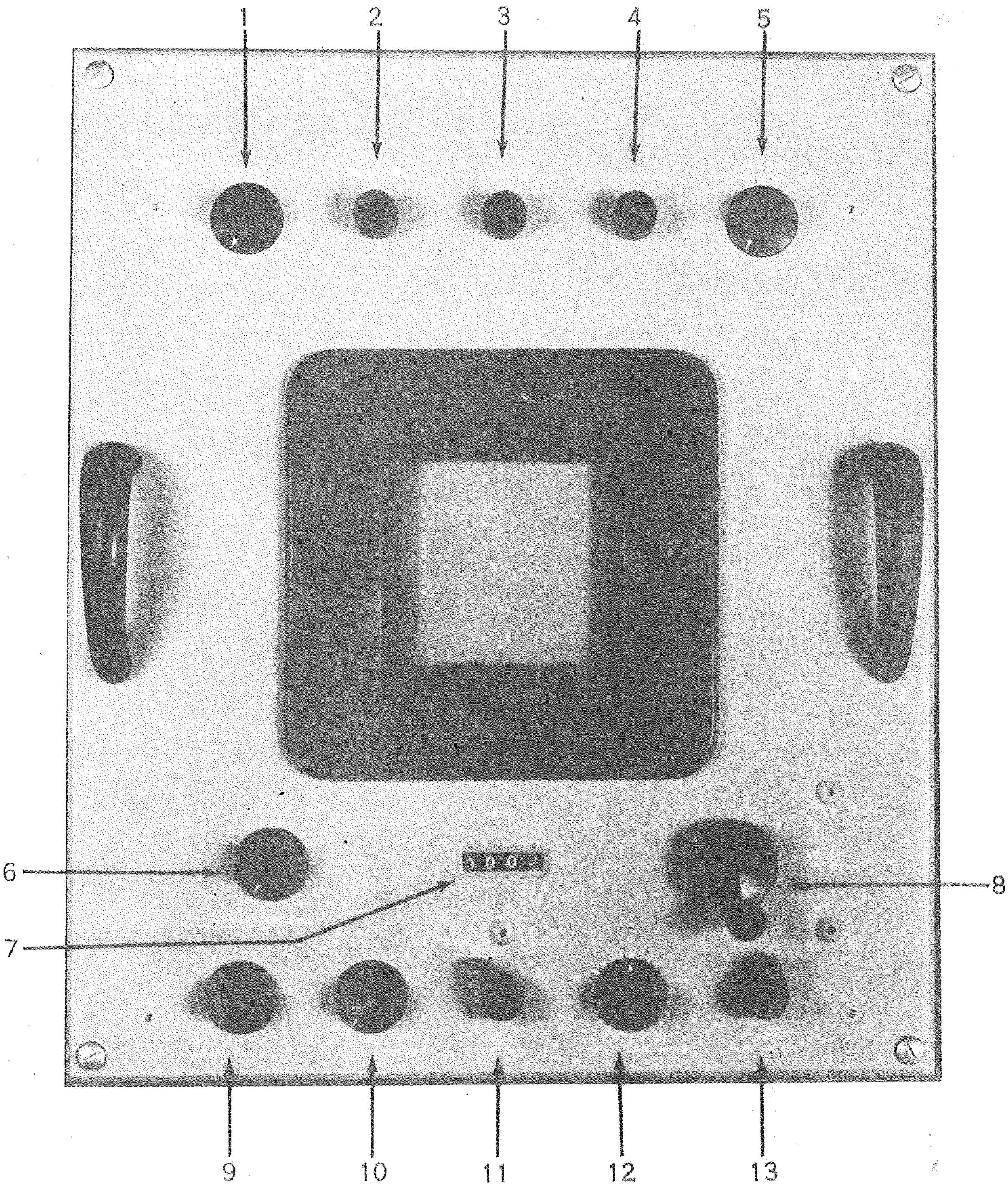

Figure 2. The A/R Indicator Panel

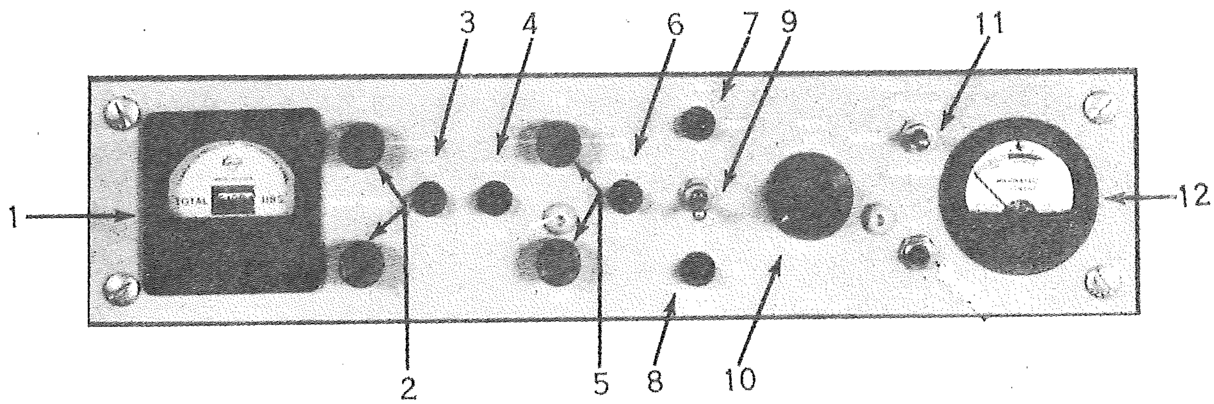

Figure 3. The Power Panel

The Power Panel (fig. 3).

(1)	ELAPSED TIME	Meter that shows the total elapsed operating and stand-by time of the console.
(2)	MAIN POWER	ON-OFF push buttons for power to entire system, except the magnetron high voltage, remote PPI and internal 115V circuit.
(3)	MAIN POWER ON	Indicator lights when the system power is on.
(4)	READY	Indicator lights when system is ready to radiate.

(5)	RADIATE	ON-OFF push buttons. ON energizes the magnetron high voltage to place the radar system in a radiate status. The OFF push button de-energizes the magnetron and places the system on standby status.
(6)	RADIATE	Indicator is lit while the system is radiating.
(7)	LONG PULSE	Indicator is lit while system is operating on long pulse (4 microsec.).
(8)	SHORT PULSE	Indicator is lit while system is transmitting on short pulse (0.5 microsec.).
(9)	PULSE	Toggle switch to select either short or long pulse.
(10)	PANEL ILLUMINATION	A rheostat that adjusts the console lights and in the extreme CCW position switches on black (ultra-violet) light.
(11)	HIGH VOLTAGE	Spring loaded, holding type switch normally in the center position. In the DECREASE position it lowers the magnetron voltage, and in the INCREASE position it raises the magnetron voltage.
(12)	MAGNETRON CURRENT	Meter shows the magnetron plate current when the system is radiating.

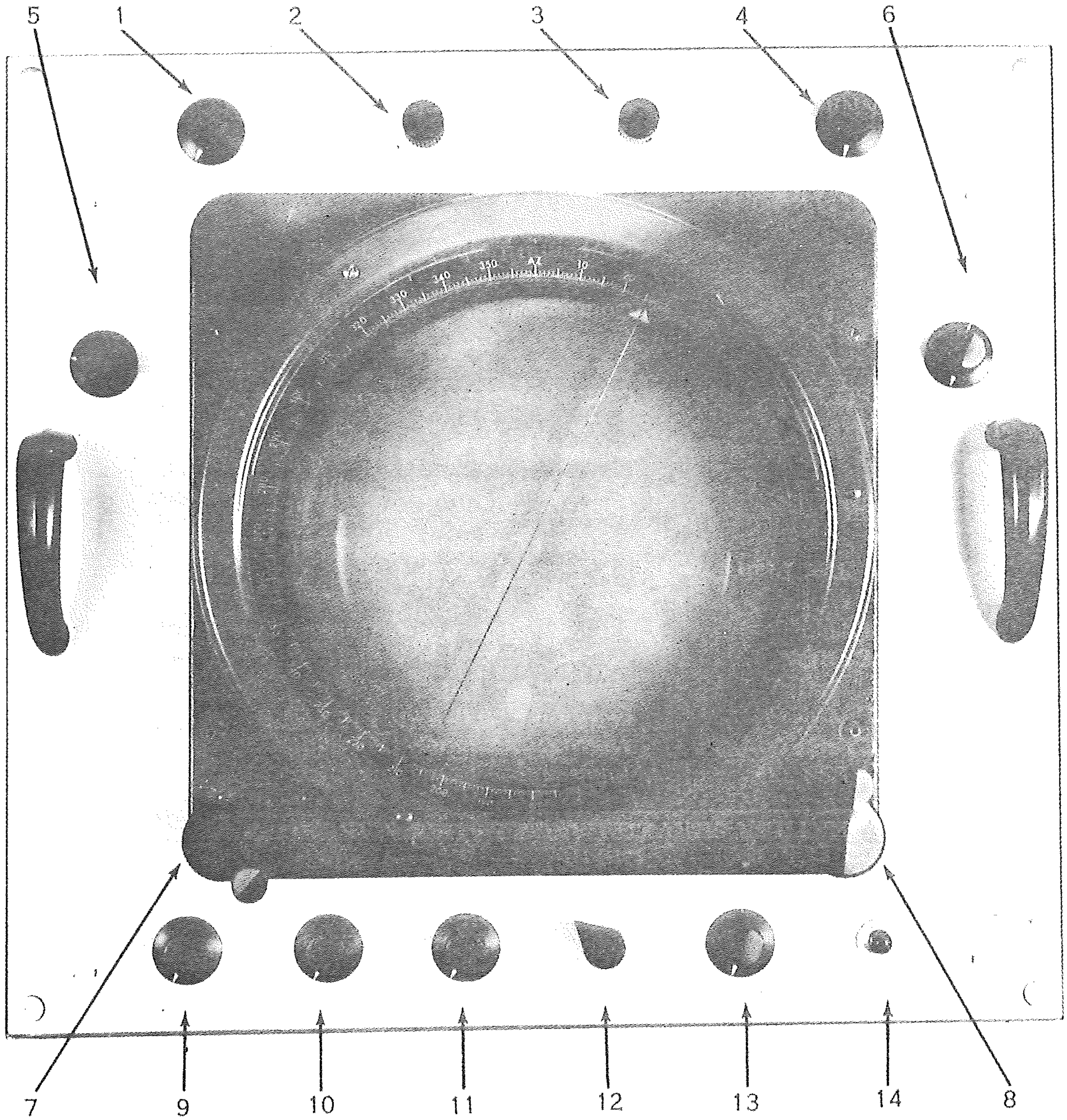

Figure 4. The Plan Position Indicator Panel

The Plan Position Indicator Panel (fig. 4).

(1)	DIMMER	Varies the illumination of the azimuth bearing ring about the PPI scope.
(2)	INTENSITY	Controls the brilliance of the sweep on the PPI scope.
(3)	FOCUS	Adjusts the focus of the image on the PPI scope for the sharpest presentation.
(4)	RANGE MARK INTENSITY	Controls the brilliance of the range marks on the PPI scope.
(5)	ANTENNA SPEED	Controls the speed of rotation of the antenna in azimuth (1 to 4 rpm).
(6)	AZIMUTH-ELEVATION	Three-position, double-value, selector switch. Controls the direction of antenna rotation for automatic azimuth operation, at the same time providing manual control of elevation scanning. Conversely, with the switch in the automatic position for elevation, manual rotation in azimuth is provided. Manual operation of the antenna is controlled by the AZIMUTH and ELEVATION HANDWHEELS.
(7)	CURSOR AND OFF-CENTER POSITION	Controls the azimuth orientation of the cursor. When the off-center PPI is used, off-centering will be in the direction of the positive, or marker end of the cursor.
(8)	AZIMUTH AUTOMATIC OUT MANUAL IN	Handwheel when pushed in allows manual rotation of the antenna in azimuth; pulled out allows automatic azimuth rotation.

(9)	OFF-CENTER MAGNITUDE	Controls the amount of displacement for off-center operation. When in extreme CCW position, the off-center is turned off.
(10)	OFF-CENTER SWEEP EXPANSION	Controls the expansion of the sweep when off-centering is used.
(11)	ISO-ECHO	Controls the iso-echo (video inversion) circuitry. In the extreme CCW position, iso-echo circuitry is off.
(12)	RANGE-MILES	Four-position switch to select the range displayed on the PPI scope. The ranges displayed are 25, 50, 125, and 250 nautical miles. <u>250 is used on long pulse only</u>.
(13)	VIDEO GAIN	Controls the gain of the video signal.
(14)	PLOTTER LIGHT	ON-OFF switch for the reflection plotter light on the PPI scope.

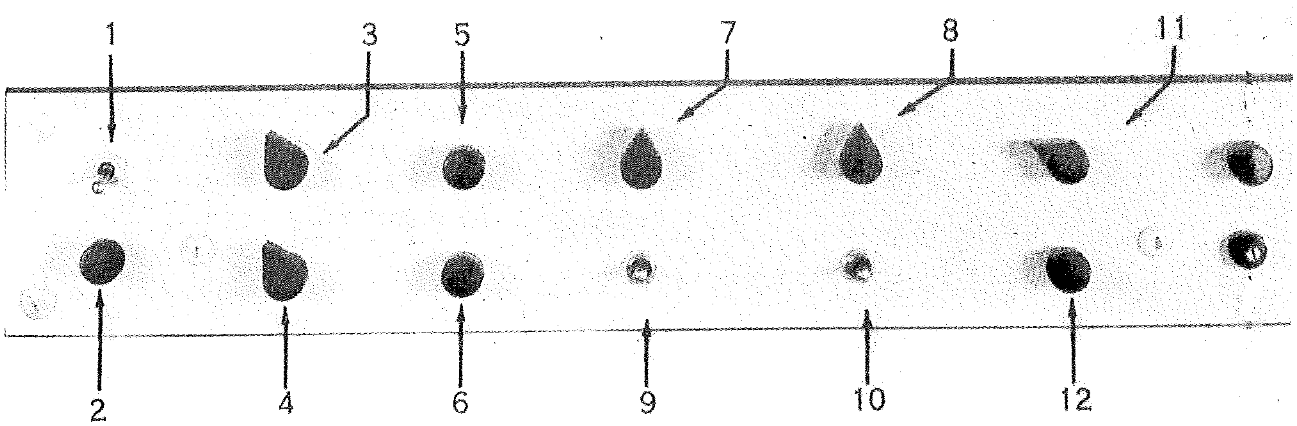

Figure 5. The Attenuator Panel

The Attenuator Panel (fig. 5).

(1)	STC	ON-OFF toggle switch for the sensitivity time control circuit.
(2)	LIN BIAS	Permits LIN BIAS voltage to be determined on TEST METER.
(3)	CONSOLE VIDEO	Switch selects either LOG or LIN receiver input for display on console scopes.
(4)	REMOTE VIDEO	Switch selects either LOG or LIN receiver input for display on the remote PPI scope.
(5)	LOG IF GAIN	Gain control for LOG receiver channel.
(6)	LIN IF GAIN	Gain control for LIN receiver channel.
(7)	LIN ATTEN IN DB	Twelve-position step-switch controls the amount of attenuation (gain reduction) of the LIN receiver channel. It is scaled from 0-33 dB, in steps of 3 dB and is used in conjunction with (9).
(8)	LOG ATTEN IN DB	Twelve-position step-switch controls the amount of attenuation (gain reduction) of the LOG receiver channel. It is scaled from 0-33 dB, in steps of 3 dB and is used in conjunction with (10).
(9)	LIN ATTEN COARSE	Three-position switch inserts large increments (33 or 66 dB) of attenuation (gain reduction) into the LIN receiver channel.
(10)	LOG ATTEN COARSE	Three-position switch inserts large increments (33 or 66 dB) of attenuation (gain reduction) into the LOG receiver channel.

(11)	AFC-MAN	Two-position toggle switch provides for automatic frequency control or manual tuning of the receiver.
(12)	LO TUNE	Adjusts the local oscillator frequency. Used with (11) in the manual position.

The Range-Height Indicator Panel (fig. 6).

(1)	DIMMER	Control varies the illumination of the digital elevation and azimuth indicators, as well as the etched glass cover on the RHI scope.
(2)	INTENSITY	Controls the brilliance of the sweep on the RHI scope.
(3)	FOCUS	Adjusts the focus of the image on the RHI scope for the sharpest presentation.
(4)	RANGE MARK INTENSITY	Regulates the brilliance of the range marks on the RHI scope and turns them off.
(5)	VIDEO GAIN	Controls the gain of the video signal on the RHI scope.
(6)	AZIMUTH	Digital dial indicates the azimuth angle of the antenna.
(7)	ELEVATION	Digital dial indicates the elevation angle of the antenna.
(8)	RANGE-MILES	Three-position switch (25, 50, or 125 nmi) to select the range displayed on the RHI scope.
(9)	ELEVATION AUTOMATIC OUT MANUAL IN	Handwheel, when pushed in, controls manual elevation scanning of the antenna. When pulled out, allows automatic RHI (elevation) scanning.

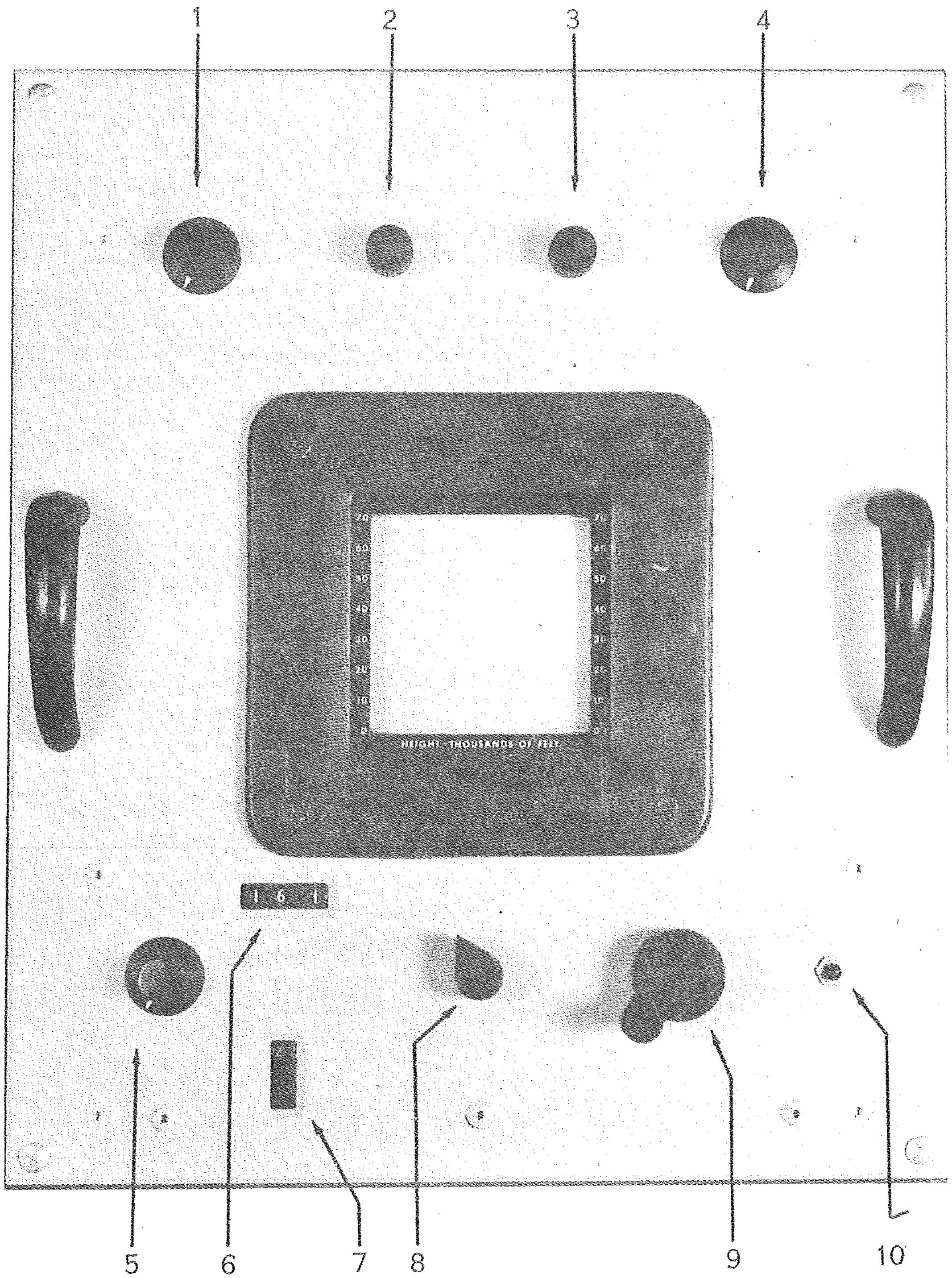

Figure 6. The Range-Height Indicator Panel

(10)	PRESS TO ALLOW MANUAL AZIMUTH ADJUSTMENT	When azimuth dial (6) does not agree with azimuth indicated on PPI scope, this button is pushed disengaging (6). The PPI sweep is then manually cranked around until it agrees with the reading of (6). The button is released and the two will now coincide.

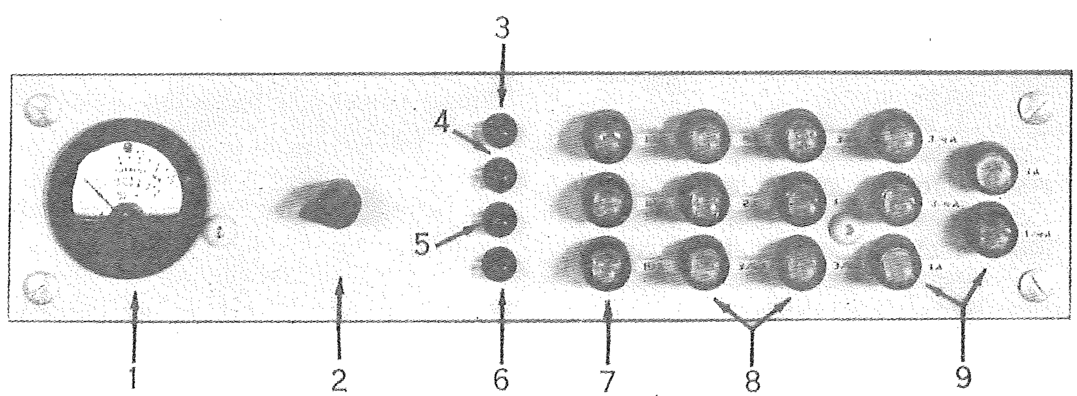

Figure 7. The Fuse Panel

The Fuse Panel (fig. 7).

(1)	TEST METER	Meter used in conjunction with LIN BIAS switch and with TEST SWITCH (2) to measure the various circuits selected.
(2)	TEST SWITCH	Twelve-position switch used to test crystal current and console power supply voltages.
(3)	ANT SERVO ERROR (EL)	Indicator lights when excessive error exists in the elevation servo system.
(4)	ANT MAL (EL)	Indicator lights when either low oil pressure exists in the antenna elevation system, or when excessive armature current in the motor generator elevation drive motor circuit is present.
(5)	ANT SERVO ERROR (AZ)	Indicator lights when excessive error exists in the azimuth servo system.
(6)	ANT MAL (AZ)	Indicator lights when either low oil pressure exists in the antenna azimuth gear system, or excessive armature current in the motor generator azimuth drive motor circuit is present.
(7)	MAIN POWER 208/220	Three fuses: Phase A, Phase B, and Phase C.
(8)	POWER SUPPLIES No. 1 No. 2	Six fuses; three for each power supply.
(9)	UNIT FILAMENTS	Five fuses.

STARTING PROCEDURES. To place the WSR-57 radar set in operation:

(1) Check intensity controls on all scopes. Make sure they are in extreme counterclockwise position (OFF).

Caution: If the intensity controls are left on, either when the system is not radiating or when the antenna remains on one azimuth for a considerable length of time, the sweeps may "burn out" the faces of the various scopes.

(2) Place the antenna rotation handwheel located on the PPI panel in the MANUAL (IN) position. This will prevent the antenna from slewing in azimuth if the position of the antenna is not synchronized with the azimuth reading on the azimuth digital dial.

(3) Place the antenna elevation handwheel located on the RHI panel in the MANUAL (IN) position and adjust it until an elevation angle of 13° shows on the elevation digital dial. This will prevent vertical slewing of the antenna as the counterweight on the antenna automatically elevates the antenna to an angle of 13° to 15° when the main power OFF button is pressed.

(4) Make certain that all personnel are clear of the antenna.

(5) Press MAIN POWER ON button.

(6) During the 5-minute warmup period after applying system power, check all blown fuse indicator lights and all functional failure indicator lights on the Fuse panel.

(7) Approximately 1 minute after the ON button on the MAIN POWER switch has been pressed, power will be supplied to the different scope panels and the various controls can then be adjusted to operational levels. Concurrent with the supplying of power to the scope panels, the azimuth and elevation servo error lights will come on.

(8) Adjust the azimuth and elevation handwheels until the servo error lights go out. This can be done by aligning the console PPI sweep with the RPPI sweep. Care must be taken not to cancel the azimuth servo error light 180° out of phase with the antenna.

(9) Place PULSE switch in SHORT PULSE position.

(10) Place SWEEP SELECTOR switch to A-SCOPE position on A/R Indicator panel, and A-SWEEP RANGE-MILES switch to 125-mile position.

(11) Place RANGE MILES switch on PPI panel on 125-mile position.

(12) Place RANGE MILES switch on RHI panel to 125-mile position.

(13) Place the CONSOLE VIDEO switch on Attenuator panel in the LIN position; the LIN ATTEN IN DB switch and the LIN ATTEN COARSE switch in the O position.

(14) Check to see that the AFC-MAN switch on the Attenuator panel is in the AFC position, and the TEST SWITCH on the fuse panel is in the OFF position.

(15) Set the OFF-CENTER MAGNITUDE, OFF-CENTER SWEEP EXPANSION, and ISO-ECHO switches on the PPI panel to the OFF position.

(16) Check to see that LIN BIAS is OFF.

(17) Test the power supply voltages. Place the TEST SWITCH consecutively in each of the six power supply positions (PS 1 and PS 2, each has three positions), at the same time observing the test meter. A reading close to the P.S. value marked on the upper scale of the test meter should be obtained for each position.

(18) Using the TEST SWITCH on the Fuse panel, check the four CRYSTAL CURRENT positions. In all four positions, readings near mid-scale of the TEST METER should be obtained. A difference of not more than 0.1 should exist between the two SIG crystals and not more than 0.2 between the two AFC crystals. If AFC XTAL 1 or XTAL 2 do not register near this position or if they exhibit "kicking" on the TEST METER, the klystron requires further tuning. If so, adjust L.O. TUNE control until "kicking" stops and meter reads near mid-scale. If this is not possible notify the electronics technician.

(19) Return the TEST SWITCH on the Fuse panel to the OFF position.

(20) Repeat the inspection of the malfunction indicator lights and blown-fuse indicator lights after the 5-minute warmup period has expired, as indicated by illumination of the READY light.

(21) Set ANTENNA SPEED control to SLOW (counterclockwise) position, the AZIMUTH ELEVATION switch to the CW position on the PPI panel and the AZIMUTH handwheel in the AUTOMATIC (OUT) position.

(22) If a malfunction is indicated and the trouble cannot be isolated and corrected by operating personnel, notify the electronics technician.

(23) Adjust INTENSITY controls on all scopes until the sweeps are just barely visible with no video or receiver gain. Too high an adjustment may "white out" the scope; too low an adjustment does not bring target presentation up to an optimum level and weaker targets may not be detected.

(24) Adjust ASTIGMATISM and FOCUS controls on A/R panel until a sharp uniform sweep is obtained.

(25) Adjust FOCUS controls on PPI panel and the RHI panel for a sharp uniform sweep.

(26) Adjust RANGE MARK AMPLITUDE on the A/R panel for the desired amplitude of range marks.

(27) Adjust RANGE MARK INTENSITY control on the PPI panel to a point where there will be approximately 350° to 355° of range marks showing. In other words, the range marks that have previously been painted at a certain azimuth should have just disappeared before the sweep starts to paint them again. Adjust the range marks on the RHI until their intensity is the same as those on the PPI scope. When the radar is operating on the 250-nmi range, proper adjustment of this control will permit 10 range marks at 25 mile intervals to be visible.

(28) Set DIMMER controls on the A/R, PPI, and RHI panel for the desired illumination of the respective digital dials and the RHI cover glass.

(29) At the end of the 5-minute warmup period, the READY lamp on the power panel will glow. Press the ON button of the RADIATE switch to start the system radiating on short pulse. For long pulse operation, 10 minutes of continuous radiation is required on short pulse. If the PULSE switch has been left in the LONG PULSE position, the system will operate in short pulse condition for 10 minutes, then will automatically switch to long pulse operation. At this point it will be necessary to press RADIATE ON switch again.

(30) Press the HIGH VOLTAGE switch on the power panel to INCREASE position until the indicator on the MAGNETRON CURRENT meter on the power panel reads 0.6 when the radar is operating on SHORT PULSE. Whenever the radar is operating on LONG PULSE the indicator on the MAGNETRON CURRENT meter should read 0.4. Never operate the magnetron in the yellow (low current) or red (high current) meter area. If the meter "kicks" or indicates unstable operation of the magnetron, press the HIGH VOLTAGE switch DECREASE until current indication on the meter is near the low edge of the green portion for a short period, then increase the magnetron current again to a normal reading. When switching from short to long pulse, it is necessary to wait 1 minute before adjusting the magnetron voltage to a 0.4 reading.

Voltage readings will vary according to the age of the magnetron and magnetron current readings other than those given above do not necessarily indicate a malfunction. It is suggested that the electronics technician be consulted for the proper operating levels for each magnetron in use.

(31) Stop antenna rotation by setting the ANTENNA SPEED control to slow, and after antenna stops place the AZIMUTH handwheel to the MANUAL (IN) position. Check the AZIMUTH digital dial on the RHI panel for agreement with azimuth indicated on PPI scope. If they do not agree, push the button on RHI panel marked PRESS TO ALLOW MANUAL AZIMUTH ADJUSTMENT, and manually rotate the antenna until the PPI sweep and AZIMUTH digital dial agree. Release the button to lock the two together.

(32) Adjust the VIDEO AMPLITUDE control on the A/R panel until the vertical amplitude of the "main bang" at the left side of the sweep just reaches the top line of the A-Scope overlay.

(33) System is now ready for tuning the klystron. Tune the klystron in the following manner:

(a) Rotate the antenna assembly manually to a known ground obstruction that will return an echo.

(b) Place the AFC-MAN switch on the Attenuator panel in the MANUAL position.

(c) While observing the A-scope, adjust L.O. TUNE control on the Attenuator panel for maximum signal amplitude above the "grass" level.

(d) Switch to the AFC position and check the A-scope to see if the maximum signal amplitude above the grass level remains the same. If not, readjust in MAN position until the amplitude remains the same in either position.

(34) Return the AZIMUTH handwheel to the AUTOMATIC (OUT) position and adjust the antenna speed control for a speed of 3 rpm.

(35) Adjust the VIDEO GAIN control on the PPI scope until the display of ground pattern and precipitation echoes are at eye optimum. This means there should be a good contrast without too much haloing or blooming. A little noise should be present on the scope.

(36) After the above procedure has been completed, it may be necessary to reset some of the above controls for optimum performance.

STANDARDIZATION OF PERFORMANCE. The following adjustment procedure for the LIN IF gain control should be used during the weekly preventive maintenance period, or at the time of maintenance of a type that would change the weather detection capability of the radar.

(1) The radar operator should adjust the A-scope video amplitude so that the amplitude of the "main bang" or saturated ground targets, reaches the top line on the A-scope overlay.

(2) The AFC circuit must be properly tuned and the technician should ensure that transmitter pulse lengths are correct. Then the electronics technician should set up the signal generator according to the section on Minimum Discernible Signal Measurements in IED Maintenance Note No. 30 dated March 9, 1962. Adjust the signal generator so that it produces a signal equivalent to -103 dBm in the LIN receiver. Console attenuator setting should be zero.

(3) With the radar set for long pulse operation, adjust the LIN IF gain control so that the top of the test signal reaches the middle reference line on the A-scope overlay.

(4) Turn the LIN BIAS on and the TEST SWITCH to SIG XTAL 2. Record the LIN BIAS voltage meter reading (scale value X10) in the Calibration Data Block of MF7-60. This value (normally between 2.5 and 3.5) becomes the standard for setting the LIN IF gain control until reestablished during the next receiver performance check. All observational data, including RAREPS, and hydrology and pilot briefing should be made with this receiver gain setting. The LIN IF gain control should not normally be touched during routine operation.

(5) Repeat (3) and (4) for short pulse operation.

(6) Disconnect the signal generator (unless it is required for other maintenance); return the LIN BIAS and TEST SWITCH to the OFF position.

(7) Measure peak transmitted power for both pulse lengths. Variation of peak power should, normally, not exceed 2 dB. The electronics technician has been instructed to provide data, in dB, on deviation of peak transmitted power from the 410kW figure used for calculation of the echo intensity graph. The method of calculation may be found on pages 4 and 5 of WSR-57 Maintenance Note No. 32, but for use here the plus and minus signs must be reversed.

(8) The LIN BIAS voltage meter reading should be checked occasionally (see item 4 above) during operation of the radar, particularly when intensity is being determined.

STOPPING PROCEDURE. To stop the WSR-57 radar the following steps should be followed:

(1) Push OFF button of Radiate switch.

(2) Place PULSE switch in SHORT PULSE position.

(3) Turn INTENSITY controls on all scopes to OFF position.

(4) Set ANTENNA SPEED control to SLOW.

(5) Place handwheel controlling rotation of the antenna in the MANUAL (IN) position.

(6) Push OFF button of MAIN POWER switch.

(7) All other controls are left in their optimum operating position so that they will require only minor readjustment when the equipment is turned on again.

STANDBY OPERATION. To place the WSR-57 radar on standby status after a period of operation, proceed as follows:

(1) Press OFF button of RADIATE SWITCH. The magnetron high voltage current indicated on the MAGNETRON CURRENT meter will return to zero (extreme left-hand side of the yellow portion of the meter). When the system is again placed in operation, it will be necessary to raise the high voltage to normal operating value by the use of the HIGH VOLTAGE switch and the MAGNETRON CURRENT meter on the power panel.

(2) Place PULSE switch in SHORT PULSE position.

(3) Turn INTENSITY and DIMMER controls on all scopes to OFF.

(4) Set ANTENNA SPEED control to SLOW and place the handwheel controlling rotation of the antenna in the MANUAL (IN) position.

(5) Place AFC-MAN switch in MAN position to prevent the automatic frequency control from searching.

(6) All other controls are left in their optimum operating position so only minor adjustment will be required when the equipment is again placed in RADIATE status.

(7) To return the radar to RADIATE status, turn up the various scope INTENSITY and DIMMER controls to optimum operating position.

(8) Place the handwheel controlling rotation of the antenna in AUTOMATIC (OUT) position and adjust the ANTENNA SPEED control for a speed of 3 rpm.

(9) Press ON button of RADIATE switch.

(10) Raise the HIGH VOLTAGE to the proper operating value by use of the HIGH VOLTAGE switch.

(11) Adjust L.O. Tune control for maximum signal amplitude and place AFC-MAN switch in AFC position.

Caution: After a period of standby status, the radar should be operated in the SHORT PULSE position for approximately 5 minutes before switching to LONG PULSE.

Scopes and Their Operation.

General. Three separate scopes are provided on the WSR-57 console for the display of echoes. These are, from left to right, a 7-inch A/R scope, 12-inch Plan Position Indicator (PPI scope), and a 7-inch Range-Height Indicator (RHI scope). A thorough understanding of the radar system and its various controls will, with practice, enable the operator to make rapid and precise adjustments for the best scope presentation of target information. The adjustment of the individual scope controls must be coordinated with the system operational controls discussed below.

LOG IF GAIN and LIN IF GAIN. These are receiver gain controls (Main Gain). The IF gain controls should be adjusted according to the instructions in "Standardization of Performance."

VIDEO GAIN CONTROLS. The A/R scope VIDEO AMPLITUDE, the PPI VIDEO GAIN, and the RHI scope VIDEO GAIN allow adjustment of the display of the scopes from a low video level to saturation of large, medium range targets. A saturation signal is most easily recognized on the A/R scope because here the signal reaches a maximum and flattens off at that point. Saturation appears on the PPI scope as a uniform illumination of maximum brightness so that variations in intensity of the illuminated area cannot be observed. Reducing VIDEO GAIN cancels the weakest echoes, but also reduces the intensity of the stronger echoes, thereby revealing the density distribution of the target area. The setting of the VIDEO GAIN controls can be made only by visual inspection of the scope display and must be a compromise between cancellation of the weaker echoes and a saturation condition of strong close-in targets.

LIN ATTEN IN DB and LOG ATTEN IN DB. These switches are used to insert varying degrees of attenuation into the receiver channel in steps of 3 dB. LIN ATTEN COARSE and LOG ATTEN COARSE switches perform the same function except that they employ large increments of attenuation; namely, 33 dB per step. The purpose of these controls is to allow the signal to be progressively reduced so that the intensity of the inner core of targets may be determined. This is commonly referred to as Gain Reduction Contouring.

CONSOLE VIDEO. This switch on the Attenuator panel allows the selection of either linear receiver amplification or logarithmic receiver amplification of the signal being fed to the main console. The REMOTE VIDEO switch controls the remote repeater scope in the same way. The result of linear receiver amplification is the presentation of saturated targets as the gain is advanced sufficiently to get a clear picture of weak targets when there are both strong and weak targets at approximately the same range. Multiple combinations of targets at different ranges could cause the same condition; namely, that the relative amplitude of the two targets would not show due to saturation of the stronger echo. The logarithmic receiver amplification has a gain characteristic which is a log function of the amplitude of the receiver echoes. When the video and receiver gain controls must be advanced to receive weaker targets, and as a consequence the stronger targets saturate, it is generally possible to get a truer proportion of the target amplitudes by using the logarithmic receiver. Basically, logarithmic receiver amplification causes the weak echoes to be amplified more than the strong echoes. For normal search usage the linear receiver amplifier should be used.

SENSITIVITY TIME CONTROL (STC). The STC circuit is a range normalization device. It compensates electronically for range attenuation by reducing the receiver gain at a rate approximately proportional to $1/r^2$, where r is the range from 10 to 125 nmi. The correct values of gain reduction for a properly calibrated STC circuit are as follows:

Range (nmi)	Gain Reduction (dB)
10	22
25	14
50	8
75	5
100	2
125	1.5

The 22-dB decrease in the first 10 miles aids in the reduction of ground clutter and decreases "blooming" of close-in echoes. The STC calibration should be checked occasionally during operation of the radar. With STC on, select a steady ground echo within 10 miles of the station and inject attenuation until the average amplitude of the target's A-scope signal coincides with the middle reference line of the A-scope overlay. Next, examine the amplitude of the same signal with STC off and the attenuator setting increased by 18 dB and 21 dB. The amplitude of the selected signal should again nearly coincide with the middle reference line of the A-scope overlay. Using a similar procedure and the range vs. gain reduction values given above, the STC calibration can be checked also between 10 and 125 miles, provided suitable targets are available. STC is used only at stations which do not have a Video Integrator and Processor (VIP). STC should not be used unless it is properly calibrated using signal generator calibration procedures. Values in the above table should be obtained within 1 dB.

The STC circuit is activated by a toggle switch on the attenuator panel of the main console.

PULSE LENGTH. The PULSE switch on the power panel selects the pulse length for the range to be examined. The 0.5-microsecond pulse is used for the 25-, 50-, and 125-mile ranges and a 4-microsecond pulse for the 250-mile range. (ALL RANGES ARE IN NAUTICAL MILES.) The pulse repetition frequency is changed coincident with the change in pulse length, 545 pulses per second on short pulse and 164 pulses per second on long pulse. Because the magnetron is required to handle a greater average power on long pulse, the switching circuit does not allow long pulse operation until the magnetron has radiated for at least 10 minutes in short pulse. The advantage of short pulse operation is that it gives a more detailed picture of nearby targets (better definition and resolution). Long pulse operation gives maximum detection sensitivity and maximum freedom from multiple trip echoes at some sacrifice in resolution.

AZIMUTH-ELEVATION. This switch on the PPI panel controls the operation of the antenna in azimuth and elevation. In the CW position the antenna rotates clockwise in azimuth and in the CCW position rotates counterclockwise. In these positions the antenna may be elevated manually using the elevation handwheel on the RHI panel. In the MANUAL (AZIMUTH) position the antenna may be rotated manually with the AZIMUTH handwheel on the PPI panel while scanning automatically in a vertical plane from -10° to +45°. To avoid excessive wear and possible damage to antenna drive system components, certain precautions should be observed. Manual controls should be operated slowly and smoothly and ample time should be allowed for moving components to come to a complete stop before reversing direction. The antenna speed control should always be set to SLOW before starting or stopping rotation of the antenna. To reduce wear on the azimuth drive gear train, the antenna should rotate clockwise on even dates and counterclockwise on odd dates.

ANTENNA SPEED. This control on the PPI panel controls the speed of rotation of the antenna in azimuth from 1 to 4 rpm. The standard operating speed for surveillance and photography is 3 rpm.

A/R INDICATOR. Located on the left side of the console, a 7-inch high-resolution cathode ray tube is provided for operation as an A and R display. Range information is displayed along the horizontal axis, and target echo amplitude is displayed along the vertical axis. This scope portrays the relative amplitude of radar echoes on any given range selected for examination. Available for A-scope presentation are ranges of 25, 50, 125 and 250 nmi. Targets appear as vertical pips extending above the horizontal sweep, with the height of each pip proportional to the intensity of the echo. Receiver noise appears as closely spaced spikes along the sweep and is commonly called "grass." The left end of the baseline represents zero range and the right end, maximum range. This indicator is used both to accurately measure intensity and range, and to determine echo characteristics along a particular azimuth.

R-SCOPE. If it is desired to make a detailed study of a particular target, or area, the R-scope presentation is used. The R-sweep is continuously adjustable from 5 to 25 miles, the range portrayed set by the R-SWEEP RANGE control. This expanded presentation is particularly valuable in such uses as distinguishing between rain and snow echoes. Rain produces a stronger echo, with a fine lacy texture, while snow echoes are weaker and of a coarser nature.

RANGE STROBE. There is an adjustable index or strobe, (negative pip) which appears on the A-scope and PPI scope sweeps. This strobe can be positioned at any point on the sweep by turning the RANGE STROBE handwheel until the strobe reaches the target. The range may then be read directly on the RANGE digital dial, directly below the scope, in nautical miles.

PEDESTAL. There is a pedestal, regulated by the PEDESTAL AMPLITUDE control, on the A-scope which permits a segment of the A-scope sweep to be elevated above the rest for examination. The length of this pedestal, controlled by the R-SWEEP RANGE control, corresponds to the range portrayed on the R-scope. The left edge of the pedestal corresponds to the strobe position.

PLAN POSITION INDICATOR. A 12-inch high-resolution, high-persistance cathode ray tube is provided in the center panel of the console. In normal use, it presents a maplike display of the area surrounding the radar out to the maximum range as selected by the RANGE switch. Controls are provided for manual scanning of a selected portion of the search area. This can be accomplished by placing the AZIMUTH-ELEVATION switch in the MANUAL (AZIMUTH) position, pushing the AZIMUTH handwheel in, and then using the handwheel to turn the antenna, first in one azimuth direction, and then in the other, over the area to be examined.

RANGE MARKERS. The range markers appear as concentric circles on the PPI scope as follows:

Range (Miles)	Number of Markers	Distance Between Markers (miles)
25	5	5
50	5	10
125	5	25
250	5 or 10	50 or 25

ALL RANGES ARE IN NAUTICAL MILES

OFF-CENTER PPI. The PPI scope is designed so that it may be off-centered in any azimuth angle to permit an expanded display of that bearing. The azimuth is determined by the marker on the end of the cursor, which is cranked to the desired angle by the CURSOR handwheel. The amount of displacement, or off-centering, is controlled by the OFF-CENTER MAGNITUDE control. Clockwise rotation of this control off-centers the sweep in the selected azimuth, up to two radii. To expand the off-center presentation, the OFF-CENTER SWEEP EXPANSION control is rotated clockwise, permitting expansion up to two radii. The Azimuth

Ring around the face of the PPI scope is significant only when the sweep origin is at the center of the scope. When the PPI display is operated in the off-center facility, a series of 10° angle markers are displayed on the face of the tube.

REFLECTION PLOTTER. A glass surface over the face of the PPI scope, which is optically constructed to minimize error of parallax, permits tracking of target echoes to determine movement, speed, growth, dissipation, etc. With the plotter light on, a point designation on the plotting surface appears in an identical position with the same point on the face of the PPI scope. Thus, for reference purposes, a target appearing on the face of the scope can be noted with a wax pencil on the plotting surface. If after a few minutes, another notation of target position is made, a line through the two notations shows the bearing of target travel. To read this bearing, turn the cursor parallel to the target line and read the bearing on the azimuth scale. The direction of echo movement can also be determined by use of a suitable directional overlay properly aligned. Note the time interval between position plots and determine distance by use of a scale or grid overlay corresponding to the range in use. Enter the Echo Movement Chart, figure 8, with the time and distance to obtain the speed of movement.

ISO-ECHO CIRCUIT. The Iso-Echo, Video Inversion circuit is used to determine the relative intensity of echoes, or of echo segments. Unlike the Gain Reduction method mentioned previously, which causes the weaker echoes to disappear first, leaving stronger inner cores visible, this method electronically reverses the procedure, and causes the stronger echoes to disappear first, leaving a presentation resembling a doughnut on the scope. The obvious advantage of this is that the original echo is always defined, with a hole, or weak spot, representing the more intense portions. In the Gain Reduction method, the outer edges, being less intense, disappear leaving only the inner cores defined. When the ISO-ECHO switch is turned clockwise through its 10 positions, any signal above a certain intensity, for each step, is blocked out. This will cause the more intense centers of the echoes to appear on the PPI scope as a hole. By the gradual use of the various steps an estimate of the relative intensity of different portions of an echo may be determined.

RANGE-HEIGHT INDICATOR. On the right side of the console is a 7-inch high-resolution, high-persistence cathode ray tube on which range-height information is displayed on rectangular coordinates. Range information corresponds to the horizontal axis, height information to the vertical axis. The scope face has an etched glass cover to display horizontal lines denoting 5,000-ft height intervals to a maximum height of 70,000 ft. This indicator is not corrected for beam width, earth curvature, standard atmospheric refraction, or antenna height. The RHI scope is used to determine the altitude of a particular storm area and to analyze its vertical structure. The AZIMUTH and ELEVATION digital dials, below

SPEED OF MOVEMENT OF RADAR ECHOES

AS A FUNCTION OF TIME AND DISTANCE TRAVELED

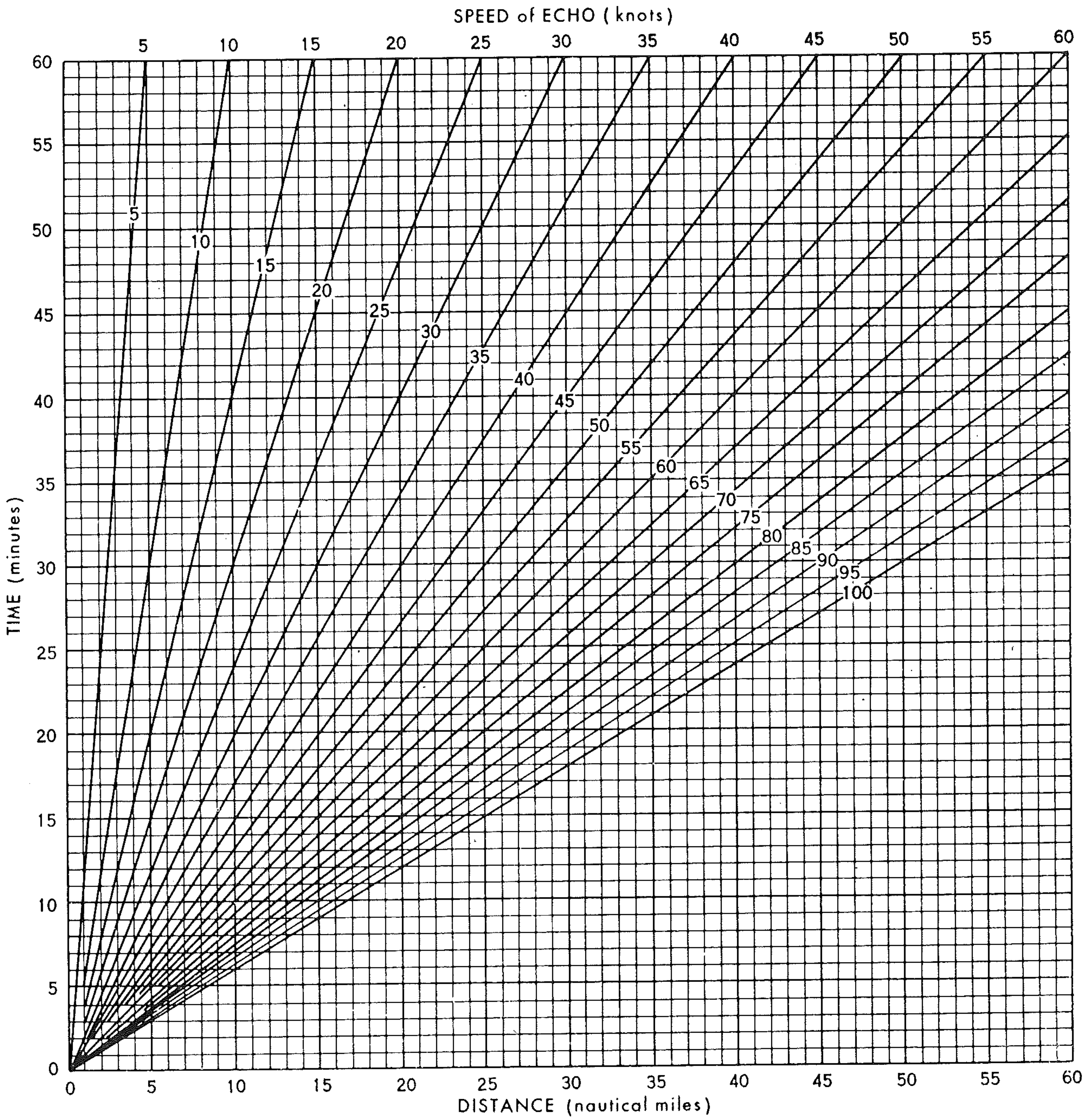

Figure 8. Echo Movement Chart

the scope, give the azimuth and elevation angles of the antenna to the nearest degree. The antenna, in RHI scan (automatic elevation), operates from -10° to +45° at a rate of six complete scans per minute. The cathode ray tube display shows a vertical profile of the target when the system is in automatic elevation scan. The system is interlocked so that automatic elevation scan will not be possible unless the antenna is in manual azimuth control. Similarly, to operate the antenna in automatic azimuth rotation implies manual control of elevation scanning.

Determining ECHO HEIGHT. When searching for the height of an echo, be sure that the antenna is moved slowly enough that system and scope response can provide an accurate scope picture. If the antenna is moved too rapidly through vertical angles, "smearing" occurs on the scope, making accurate readings impossible. The readings taken from the scope must be corrected for beam width, earth curvature, atmospheric refraction, and antenna height above sea level (echo heights are reported in hundreds of feet above MSL). The first three corrections are incorporated in the table below, from which a graph or nomogram may be constructed for use at the radar console.

RHI CORRECTIONS

RANGE	TOP	BASE	RANGE	TOP
5	- 500	+ 600	70	-4100
10	-1000	+1200	75	-4100
15	-1400	+1800	80	-4200
20	-1800	+2500	85	-4200
25	-2200	+3200	90	-4200
30	-2500	+3800	95	-4100
35	-2800	+4500	100	-4000
40	-3200	+5300	105	-3900
45	-3400	+6100	110	-3700
50	-3600	+6900	115	-3500
55	-3800	+7900	120	-3200
60	-3900	+8800	125	-2800
65	-4000	-----	---	-----

RHI ACCURACY TEST. In order to insure that the heights indicated by the RHI scope are accurate, RHI accuracy tests will be conducted at specific intervals. Whenever an RHI test is conducted, and is satisfactory, enter RHIOK in the Remarks column of MF7-60 but do not transmit.

Once a week, at 1435 GMT each Monday, the following test will be made to determine if the RHI is properly aligned. If the criteria given below can not be obtained, malfunctioning is indicated and the electronics technician should be notified immediately.

1. Set RHI on 25-mile range.

2. Raise the RHI sweep until it exactly intersects the 70,000-ft line at 25 miles.

3. Read the elevation angle. The value should be 27.6°. A reading of 27° or less, or 28° or more, indicates the need for correction.

4. On each range adjust the sweep line so that the fifth range mark is positioned on the 70,000-ft line, within 1/16 inch of the right hand vertical line on the bezel. The other range marks should then be positioned as follows:

Range Mark No.	Position (ft)
1	12,600 to 15,400
2	26,600 to 29,400
3	40,600 to 43,400
4	54,600 to 57,400
5	70,000

During the first week of January and every 3 months thereafter, a more comprehensive test will be taken. Each WSR-57 station will contact the FAA Air Traffic Control personnel in their vicinity and arrange to set up the test program. The basis of the test will be the measurement of the height of a selected aircraft in level flight. The height reported by the pilot's altimeter will be corrected by use of current Radiosonde data and compared with the height computed from the elevation angle of the WSR-57 antenna. The following guidelines are suggested:

1. Before starting the test, be sure the indicated elevation angle is 0°, when the antenna is pointed exactly horizontal (use a plumb bob).

2. Run the test on a fair weather day.

3. Advise the FAA that you wish to track an aircraft which will be flying primarily along one azimuth on approach or outbound from the airfield, since it will then be easier to track. An aircraft flying above 24,000 feet and between 25 and 75 miles of the station will yield more satisfactory results.

4. Use automatic elevation scanning and determine height of the aircraft by using the midpoint of the echo on the RHI scope. If the echo touches the bottom of the RHI scope, the exact midpoint can not be determined and the sampling should not be used. A correction for earth curvature should be applied.

5. Record elevation angle as a function of range at regular intervals.

6. Construct a rough data sheet with the following headings: range, aircraft height (from FAA), computed height, height difference (aircraft minus WSR-57).

If the height difference (aircraft minus WSR-57) is within the limits determined by a 0.5° angle for the range concerned, the RHI scope is accurately indicating the height of radar echoes. Using data gathered in the above manner, the accuracy of the scope is determined in the following manner. Height of the antenna is 1,300 feet MSL and earth curvature correction at 40 nautical miles is 1,000 feet.

Range	Aircraft height (MSL) from FAA	Midpoint of echo on RHI scope	Computed height	Height diff acft minus WSR-57
40	10,000	8,000	10,300	-300

The computed height, 10,300 feet, in the above example is found by adding the heights from the RHI (midpoint), earth curvature and MSL height of the antenna (8,000 + 1,000 + 1,300). At 40 nautical miles the distance in feet for 0.5° is 2,200 feet. As the height difference (300 feet) is within the limits determined by 0.5° angle criteria (2,200 feet), the RHI scope is accurately indicating the height of the radar echoes.

If the average difference between the actual aircraft and radar observed aircraft heights is greater than 0.5°, the test should be repeated. After repeating, if the difference is still greater than 0.5°, malfunctioning is indicated and the electronics technician should be notified immediately. A copy of the results of this test should be sent to the Regional Headquarters.

ORIENTATION (AZRAN CHECK). Check the orientation of the antenna and the range indication of the set once daily at the time of the 1500 GMT observation and enter an appropriate note on MF7-60 (Radar Weather Observations) under "Remarks."

To check the orientation and range indication, first tune the receiver and make the necessary adjustments to place the equipment in optimum operating condition; then place the range selector switch in the shortest range that will encompass the ground return, and note the indicated azimuth and range of a ground target whose direction and distance are known. A more accurate determination of the AZRAN of the orientation check point can be made if sufficient attenuation is injected into the signal path of the radar until the echo on the A-scope is slightly above the threshold level. This procedure will help eliminate the effect of beam width. If the azimuth and range indications are satisfactory, record a note, "AZRAN OK," under the "Remarks" column on MF7-60 but do not transmit this note over any teletypewriter circuit. If either the indicated azimuth or range are improper for the target selected, this indicates a malfunctioning of the equipment. Notify the electronics technician immediately.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

WSR-57 RADAR LOCATIONS

Radar Site	Latitude	Longitude
Amarillo, Tex.	35°14'N	101°42'W
Apalachicola, Fla.	29°44'N	84°59'W
Athens, Ga.	33°57'N	83°19'W
Atlantic City, N.J.	39°27'N	74°35'W
Bristol, Tenn.	36°26'N	82°08'W
Brownsville, Tex.	25°54'N	97°26'W
Brunswick, Maine	43°54'N	69°56'W
Buffalo, N.Y.	42°56'N	78°44'W
Cape Hatteras, N.C.	35°16'N	75°33'W
Centreville, Ala.	32°52'N	87°15'W
Charleston, S.C.	32°54'N	80°02'W
Chatham, Mass.	41°39'N	69°57'W
Cincinnati, Ohio	39°04'N	84°40'W
Daytona Beach, Fla.	29°11'N	81°03'W
Des Moines, Iowa	41°32'N	93°39'W
Detroit, Mich.	42°14'N	83°20'W
Evansville, Ind.	38°03'N	87°32'W
Fort Worth, Tex.	32°50'N	97°03'W
Galveston, Tex.	29°18'N	94°48'W
Garden City, Kans.	37°56'N	100°43'W
Grand Island, Nebr.	40°58'N	98°19'W
Hondo, Tex.	29°22'N	99°10'W
Huron, S.D.	44°23'N	98°13'W
Jackson, Miss.	32°19'N	90°05'W
Kansas City, Mo.	39°06'N	94°35'W
Key West, Fla.	24°33'N	81°45'W
Lake Charles, La.	30°07'N	93°13'W
Limon, Colo.	39°12'N	103°42'W
Little Rock, Ark.	34°44'N	92°14'W
Marseilles, Ill.	41°22'N	88°41'W
Medford, Oreg.	42°05'N	122°43'W
Memphis, Tenn.	35°21'N	89°52'W
Miami, Fla.	25°43'N	80°17'W
Midland, Tex.	31°56'N	102°12'W
Minneapolis, Minn.	44°53'N	93°13'W
Missoula, Mont.	47°02'N	113°59'W

(continued)

Radar Site	Latitude	Longitude
Monett, Mo.	36°53'N	93°54'W
Nashville, Tenn.	36°15'N	86°34'W
Neenah, Wis.	44°13'N	88°33'W
New York City, N.Y.	40°46'N	73°59'W
Oklahoma City, Okla.	35°24'N	97°36'W
Patuxent River, Md.	38°17'N	76°25'W
Pensacola, Fla.	30°28'N	87°12'W
Pittsburgh, Pa.	40°32'N	80°14'W
Sacramento, Calif.	38°35'N	121°29'W
St. Louis, Mo.	38°45'N	90°23'W
Slidell, La.	30°19'N	89°46'W
Tampa, Fla.	27°58'N	82°32'W
Waycross, Ga.	31°15'N	82°24'W
Wichita, Kans.	37°39'N	97°25'W
Wilmington, N.C.	34°16'N	77°55'W

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

WSR-1 RADAR OPERATING INSTRUCTIONS

General. The WSR-1 radar is a modified APS-2 (Navy) system mounted in a vertical chassis (fig. 1). It operates in the S-band at a frequency of 2,840 Mc with a wavelength of 10.5 cm. It has a maximum range of 150 nmi and its peak power output is 50 kW.

Operating Controls and Their Functions. The operating controls for the Model WSR-1 radar set are all located on the panel receiver-indicator (see figs. 2, 3, 4, and 5). Those most frequently used are provided with knobs or toggle switches. Those seldom used are of the screwdriver type.

Operating Controls for Model WSR-1 Radar.

(1)	RECEIVER GAIN	Potentiometer adjustment for regulating the overall amplification (gain) provided by the receiver. Resetting this control will also vary the brilliance of the images on all scopes connected to the receiver.
(2)	ANTENNA (LR)	A three-position toggle switch controls the direction of rotation of the antenna. With switch (4) in ON position the antenna will turn clockwise when this switch is in R position and counter-clockwise when it is in L position. With switch (4) in OFF position the antenna may be rotated manually when this switch is in center position.
(3)	ANTENNA SPEED CONTROL	A continuously variable control for adjusting antenna speed from 1 to 6 rpm.

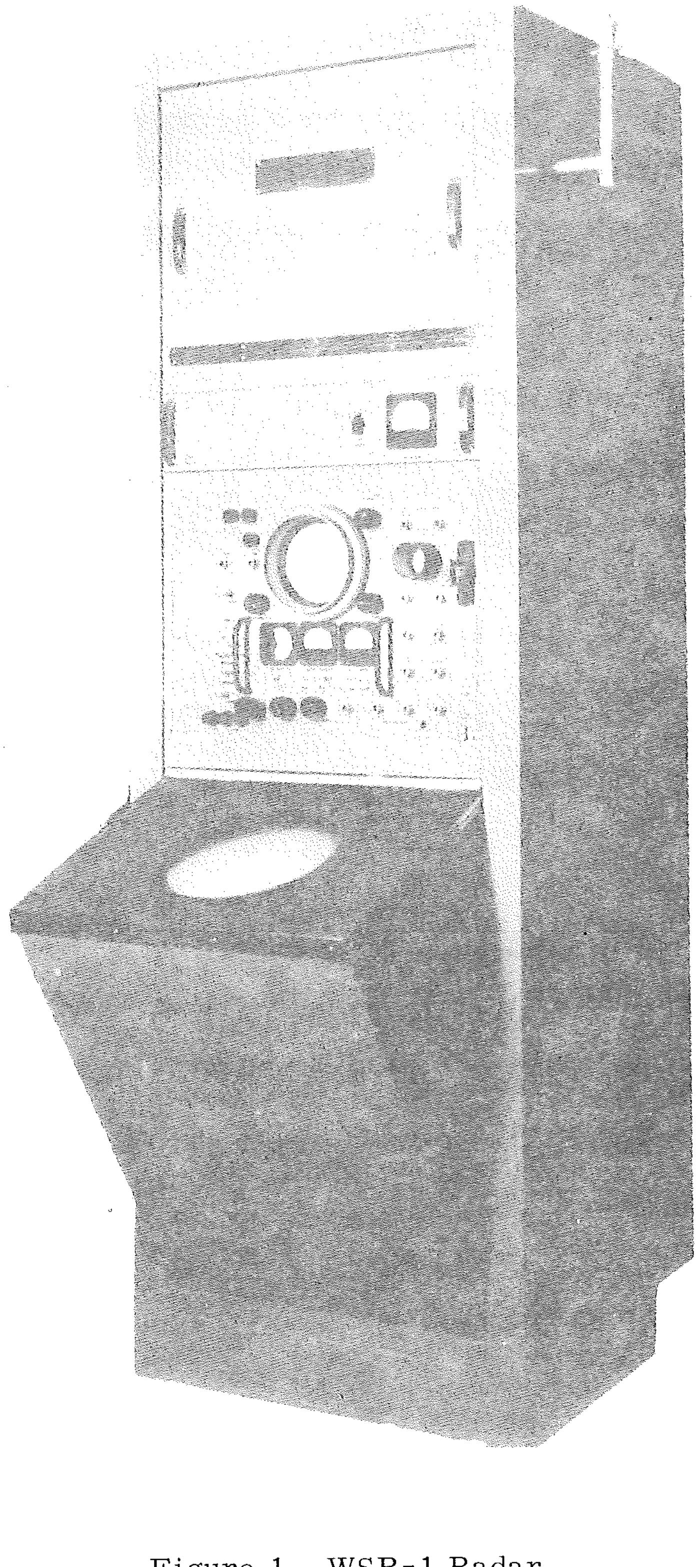

Figure 1. WSR-1 Radar

(4)	ANTENNA (ON OFF)	A toggle switch for starting and stopping rotation of antenna.
(5)	TRANS HV	A spring return toggle switch which, when placed in the START position, turns on the high voltage sections of the transmitter.
(6)	TRANS FIL	Toggle switch for controlling the power to the filaments of all tubes, the transmitter blower motor, and the receiver high voltage section.
(7)	POWER	Toggle switch for turning on and off power to all units of the radar set.
(8)	TILT	A spring return, three-position toggle switch for changing the tilt of the antenna.
(9)	RANGE MARKS	A potentiometer control for regulating the brilliance of the range marks on all scopes.
(10)	CRYSTAL CURRENT	Toggle switch for turning on crystal-current meter.
(11)	RANGE SWITCH	(5-25-50-150 or 5-25-50-100/200) A four-position switch for selecting the range.
(12)	MICRO SEC (1-2)	Two-position switch for selecting the transmitted pulse. (1 or 2 micro-seconds)
(13)	TRANS CURRENT	Two-position switch controlling the input to the TRANS CURRENT meter. In the RCT position, the meter indicates the current flowing from the rectifier to the transmitter and in the MOD position the meter indicates the current flowing to the output tube.

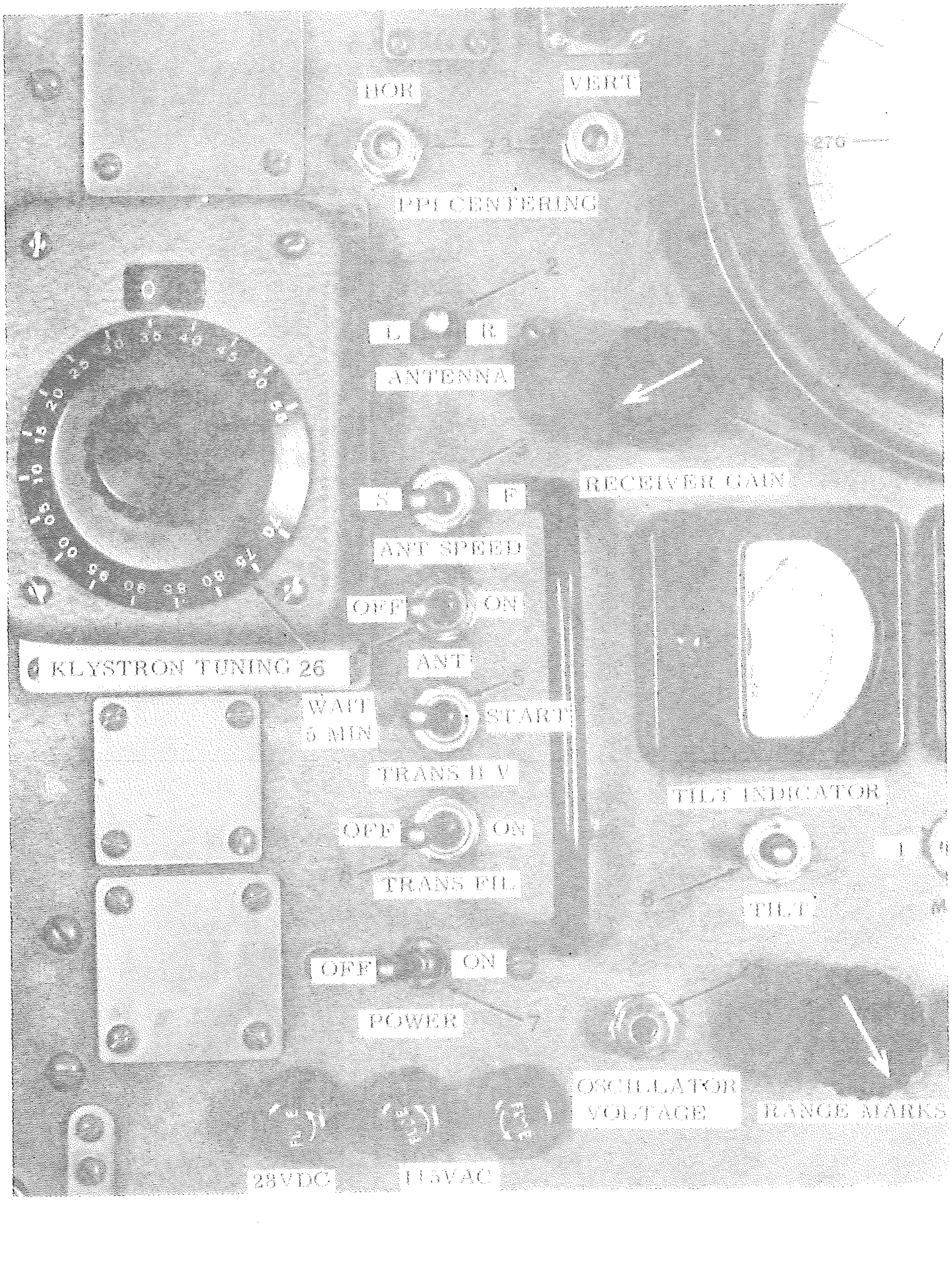

Figure 2. Left Section Receiver Panel

(14)	A-SCOPE SWITCH	A three-position switch controlling the input to the A-scope. In position "1," the A-scope may be used in checking the receiver; in position "2," it may be used in checking the transmitter; and in position "3," the target image is placed on the scope.
(15)	VIDEO GAIN	A potentiometer control for varying the amount of video amplification.
(16)	A-SCOPE FOCUS	A screwdriver adjustment for focusing the image on the A-scope.
(17)	A-SCOPE BRILL	A screwdriver adjustment for regulating the brilliance of the image on the A-scope.
(18)	PPI FOCUS, LOCAL	A screwdriver adjustment for focusing the image on the local PPI scope.
(19)	PPI FOCUS, REMOTE	A screwdriver adjustment for focusing the image on the remote PPI scope.
(20)	BRILL VERNIER, LOCAL	A screwdriver adjustment for regulating the brilliance of the image on the local PPI scope.
(21)	BRILL VERNIER, REMOTE	A screwdriver adjustment for regulating the brilliance of the image on the repeater's PPI scope.
(22)	SWEEP AMPLITUDE (5-25-50-150; or 5-25-50-100/200)	Screwdriver adjustments used to regulate the length of the sweeps at each range. When changing ranges from one scope to another it will be necessary to reset these controls.

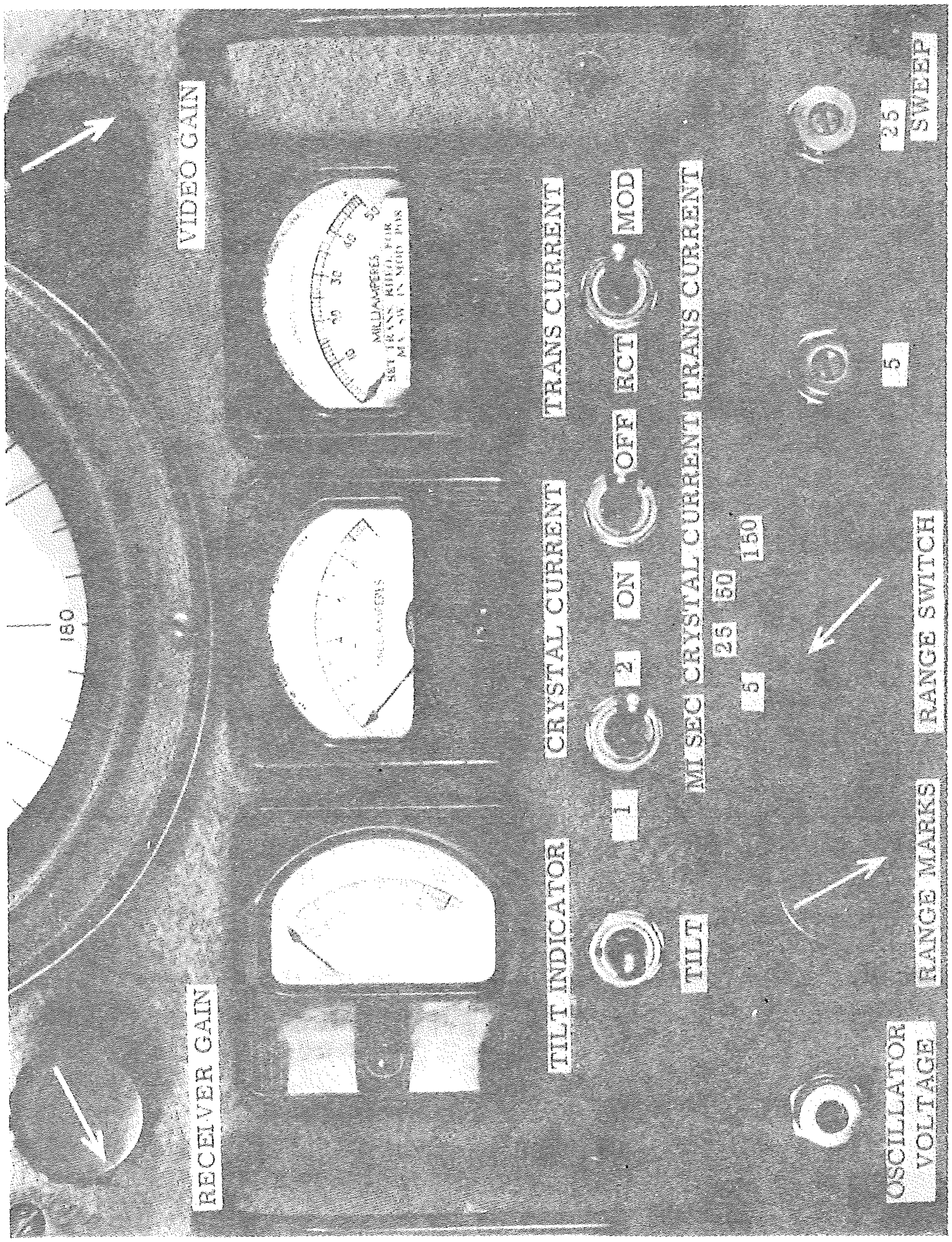

Figure 3. Center Section Receiver Panel

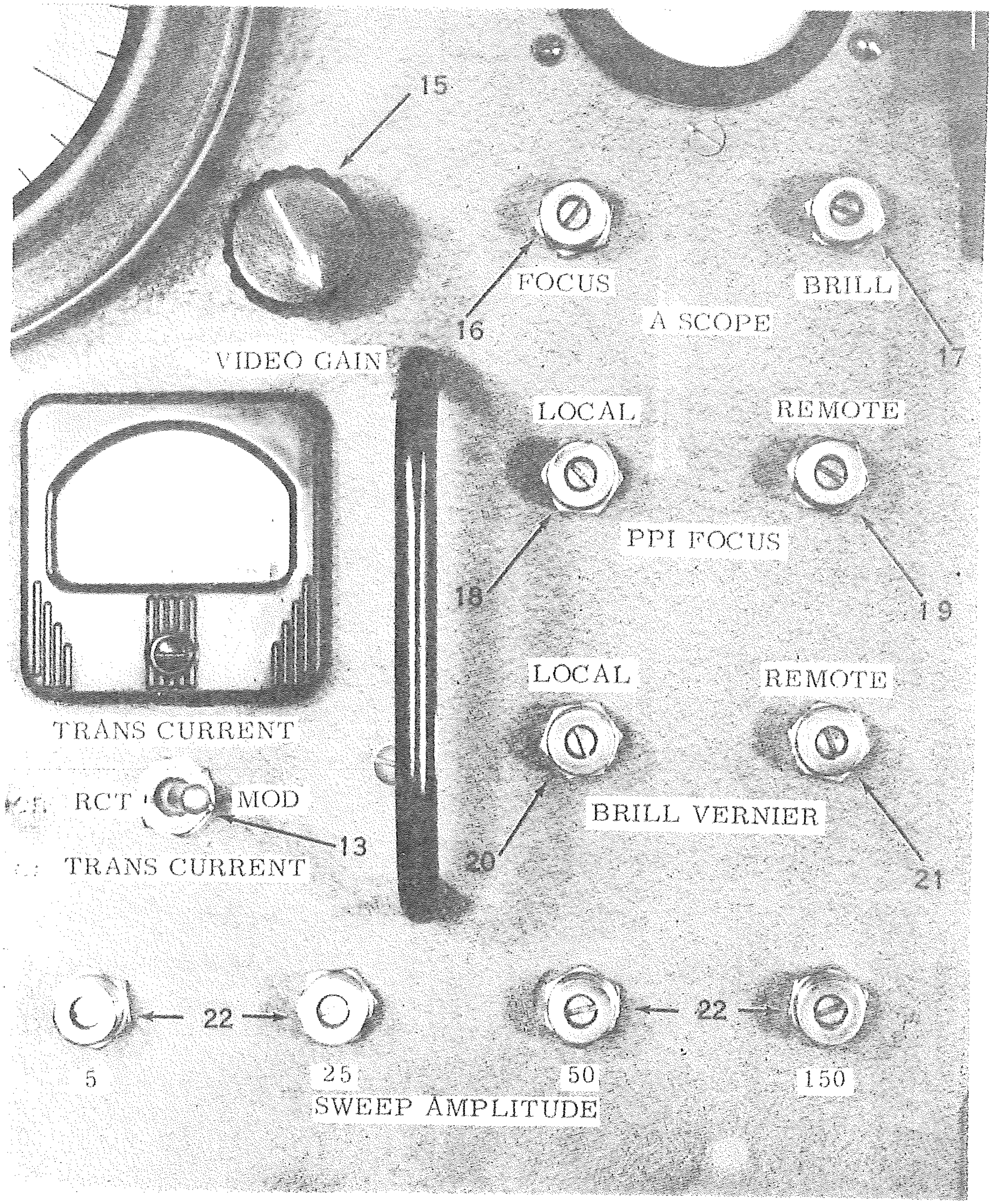

Figure 4. Right Section Receiver Panel

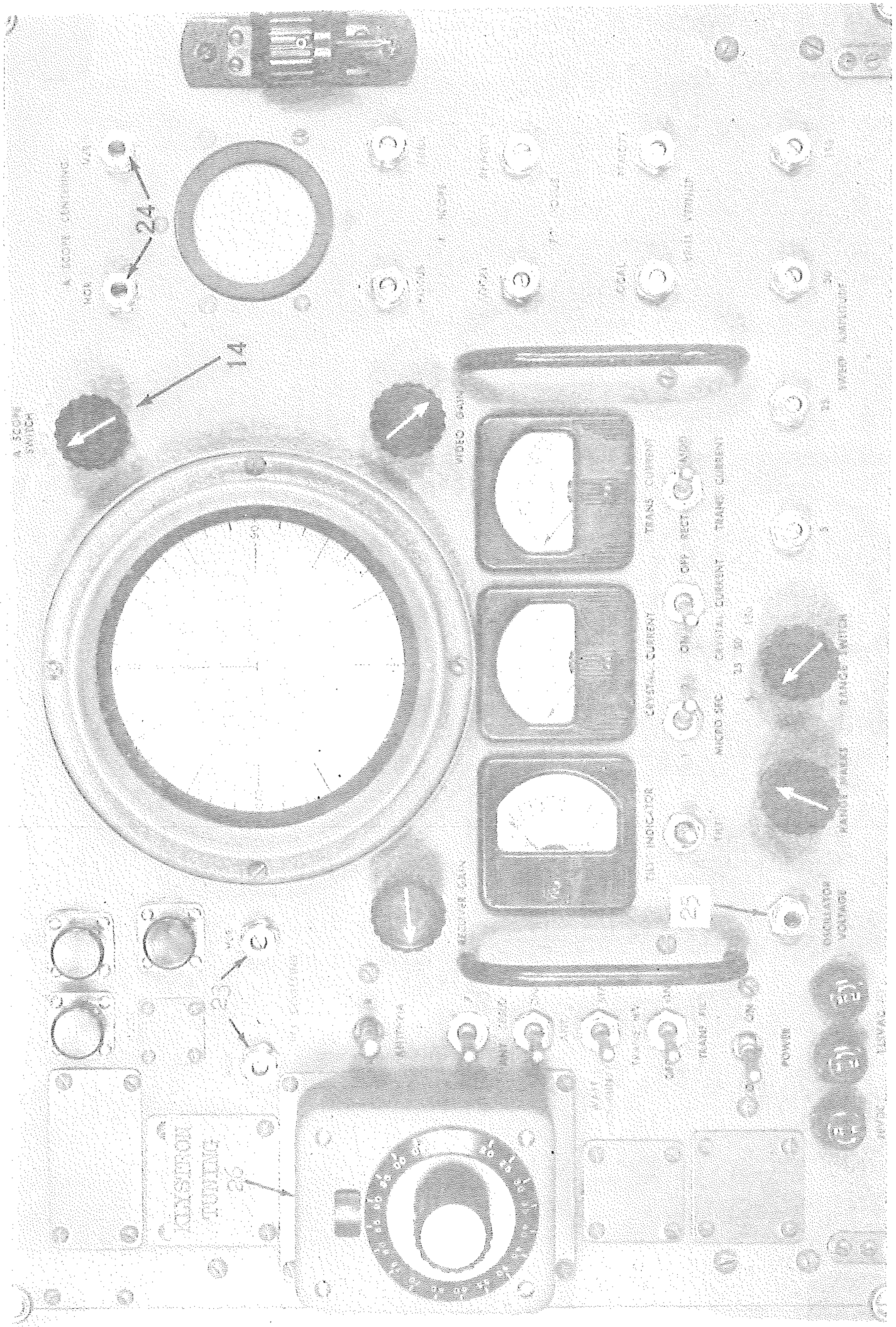

Figure 5. Receiver Panel

(23)	PPI CENTERING (HOR VERT)	Screwdriver adjustments regulate the position of the sweep on the local PPI scope.
(24)	A-SCOPE CENTERING (HOR VERT)	Screwdriver adjustments regulate the position of the sweep on the A-scope.
(25)	OSCILLATOR VOLTAGE	A screwdriver adjustment used to tune the oscillator circuit.
(26)	KLYSTRON TUNING	Use in conjunction with the 2-inch A-scope to tune the receiver.

STARTING PROCEDURE. To place the Model WSR-1 radar set in operation, proceed as follows:

(1) Make sure that the equipment is clear of personnel.

(2) Depress START button to turn on power to the motor generator. (This switch is located apart from the receiver-indicator panel and is usually mounted on the side or rear of the radar rack.)

(3) Place POWER switch in the ON position.

(4) Place TRANS FIL switch in the ON position.

(5) Place ANTENNA SPEED CONTROL in SLOW position and turn ANT switch to ON.

Caution: Do not operate the radar when antenna rotation is sluggish due to extremely cold temperatures.

(6) Place CRYSTAL CURRENT switch in ON position and note the meter reading. This reading should be between 0.4 and 0.6 milliamperes. If the crystal current does not fall between these limits, or if no crystal current appears after waiting approximately 60 to 90 seconds after TRANS FIL switch has been thrown, consult "Handbook of Maintenance Instructions for U.S.W.B. Search Radar Model 1."

(7) Note sweeps of all scopes. Set the brilliance so that the sweep is just visible without video or receiver gain and adjust focus so that sweep is fairly narrow and well defined. If necessary, center the sweep by use of the appropriate HORIZONTAL and VERTICAL controls. The sweep on the remote 12-inch PPI may be centered by adjusting its deflection coil.

Caution: Continuous use of too high brilliance on any of these sweeps will damage the face of the Cathode-Ray tube.

(8) Read TEST METER located above receiver indicator on the panel of the driver amplifier. TEST METER switch should be set consecutively in each of the five numbered positions, and should read as follows:

POSITION	READING (VOLTS)
1 (direct reading)	90
2 (multiply reading by 2)	720
3 (multiply reading by 10)	1550
4 (multiply reading by 10)	900
5 (test circuits off)	

These readings should be within ±10%. These will change when the HIGH VOLTAGE switch is thrown.

(9) RECEIVER GAIN and VIDEO GAIN shall be turned to extreme clockwise position. After warmup these controls may be adjusted as required. Equipment operates best with VIDEO GAIN control in the extreme clockwise position.

(10) RANGE MARKS control should be turned clockwise until the range marks are clearly seen on the PPI and A-scopes. All ranges are in nautical miles.

(11) The A-SCOPE switch shall be set to position one. The range marks shall appear as a series of sharp vertical pips and noise shall appear as a fringe on the A-scope sweep line.

(12) After the TRANS FIL has been on at least 5 minutes the TRANS H.V. switch is thrown to START position momentarily and the TRANS CURRENT switch set to MOD. In this position the TRANS CURRENT meter should read 7.3 mA. The TRANS CURRENT switch is then set to RCT position and should read approximately 3 mA higher than the previous reading. If the meter shows any tendency to "kick" to a higher reading the TRANS FIL switch shall IMMEDIATELY be thrown to the OFF position. The TRANS FIL switch then is turned on again and an additional warmup period of 2 minutes is allowed before the TRANS H.V. switch is turned on again. If this "kicking" continues after 15 minutes of warmup, the equipment should be turned off and the technician notified.

(13) With the antenna rotating in horizontal position ("0" position on TILT meter) pick out a distant echo on both scopes. The A-SCOPE switch should be put in position "1." Stop rotation of antenna. OSCILLATOR VOLTAGE should be adjusted for maximum crystal current. The Klystron should be tuned for maximum amplitude of received echo as viewed on A-scope. This is accomplished by adjusting tuning knob located to the center and right side of the Klystron. On some models of this radar Klystron tuning is accomplished by adjusting KLYSTRON TUNING dial. The last two steps will be repeated until maximum echoes are obtained at maximum crystal current. Adjust the amount of crystal current to read 0.4 mA on CRYSTAL CURRENT meter. This is accomplished by adjusting the crystal cavity coupler plunger. This is located on the crystal mixer assembly on the back side of the transmitter chassis. To reduce crystal current turn counterclockwise; to increase current turn clockwise.

(14) If no echoes appear the Klystron tuning control should be adjusted slowly from one end of its range to the other. After tuning the Klystron a short distance, the crystal current will fall to zero; as this occurs adjust the OSCILLATOR VOLTAGE pot until crystal current is again present. Continue tuning until echoes are seen on the PPI or A-scope.

(15) In tuning the Klystron the operator will encounter two frequencies that produce echoes on the scopes. The higher frequency should be used.

STOPPING PROCEDURE. To turn the WSR-1 off, the following steps are required:

(1) Place antenna switch in OFF position.

(2) Place TRANS FIL switch to OFF position.

(3) Place POWER switch to OFF position.

(4) Actuate motor generator STOP button.

The equipment is now turned off.

STANDBY OPERATION. It may be desirable to operate the equipment in a standby condition. This eliminates the usual warmup period before each observation. In this case, the transmitter high voltage may be removed by momentarily turning off the TRANSMITTER FILAMENT switch, then immediately switching it back on again. The radar remains heated and ready for operation by switching on TRANSMITTER H.V.

Scopes and Their Operations. The WSR-1 radar uses three scopes: a 2-inch A-scope, a 5-inch local PPI scope, and a 12-inch remote PPI scope.

A-SCOPE. The 2-inch A-scope is used to indicate amplitude versus range as presented by a target in the radar beam. The amplitude of the echo display on the screen is an indication of the reflectivity of the target. The A-scope is also used to tune the receiver, and the transmitter, using the A-scope switch (14).

PPI SCOPES. The 5-inch and the 12-inch PPI scopes present a map-like image on a horizontal plane of all targets within the radar's range, capable of being detected. The sweep on the scope corresponds to the rotation (scan) of the antenna to indicate azimuth, while the distance from the start of the sweep to the indicated echo on the scope determines the range of the target. A choice of 5, 25, 50, and 150 miles range presentation is available,* with range markers as follows:

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*On some sets the range scale reads 5, 25, 50, 100/200. Range Markers will be the same as above except for the 100/200 range where the number of markers will vary, depending on the circuitry performance.

Range Switch	Number of Markers or Circles	Interval Between Markers
5-miles	5	1 mile
20-miles	5	5 miles
50-miles	5	10 miles
150-miles	6 to 7	20 miles

ALL RANGES ARE IN NAUTICAL MILES

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

OPERATING INSTRUCTIONS FOR WSR-1A, WSR-3 AND WSR-4 RADARS

General. The WSR-1A, WSR-3 and WSR-4 radars are essentially the same systems as far as circuitry and operating procedures are concerned. All are modified APS-2 (Navy) radars, with a maximum range of 180-200 nautical miles. All are S-band radars operating at a frequency of 2840 Mc, with a wavelength of 10.5 cm. Peak power is 50 kW. The WSR-3 and WSR-4 are mounted in a three-panel, horizontal chasis (fig. 2).

WSR-1A. The WSR-1A consists of the receiver-indicator of the WSR-3, fitted with the 2-inch A-scope of the WSR-1 and the controls necessary to operate it (fig. 1). This unit is mounted in the vertical chasis of the WSR-1. These additions necessitated moving a few controls on the panel, but the CONTROLS section on the WSR-3, and the operation procedures, remain valid. To operate the A-scope, refer to "WSR-1 Radar Operating Instructions."

WSR-4. The WSR-4 is essentially a WSR-3, with a Traveling Wave Tube Assembly and its power supply introduced. This increases the receiver sensitivity, thereby improving the detection capabilities of the system.

The Traveling Wave Tube Assembly includes a HELIX METER, mounted on the front panel of the assembly. This is located in the lower half of the console, on the right side (behind access door). The HELIX METER will be monitored by the operator. If, at any time, this meter should read in excess of 25 mA, the system will be turned off immediately to prevent damage to the Traveling Wave Tube.

Operating Controls and Their Functions. All the operating controls for the WSR-3 are located on the console. distributed among three panels. These are, from left to right, the A-scope Panel, the Local (5-inch) Plan Position Indicator Panel, and the Remote (12-inch) Plan Position Indicator.

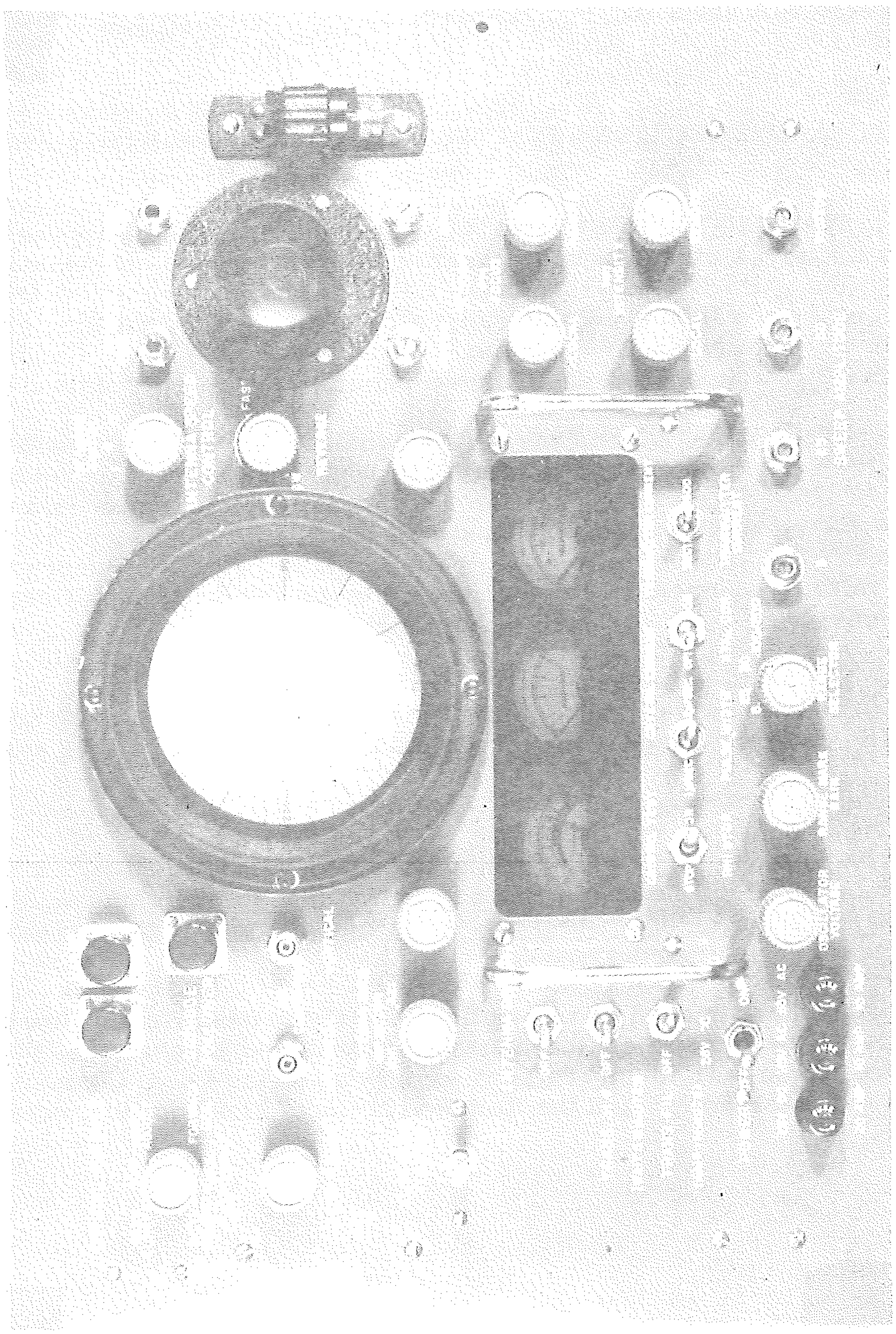


Figure 1. WSR-1A Receiver-Indicator

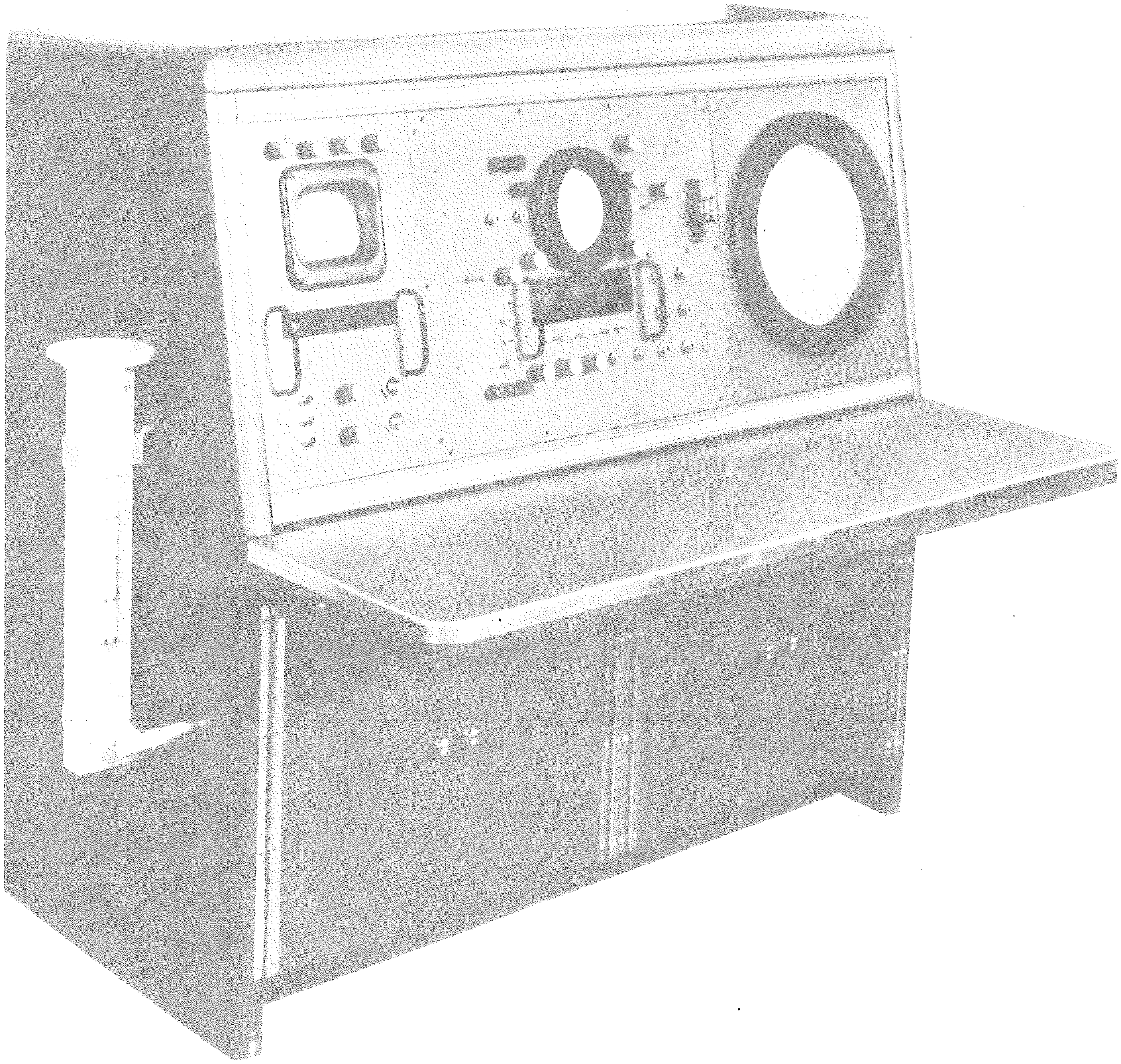


Figure 2. WSR-3 and WSR-4 Console

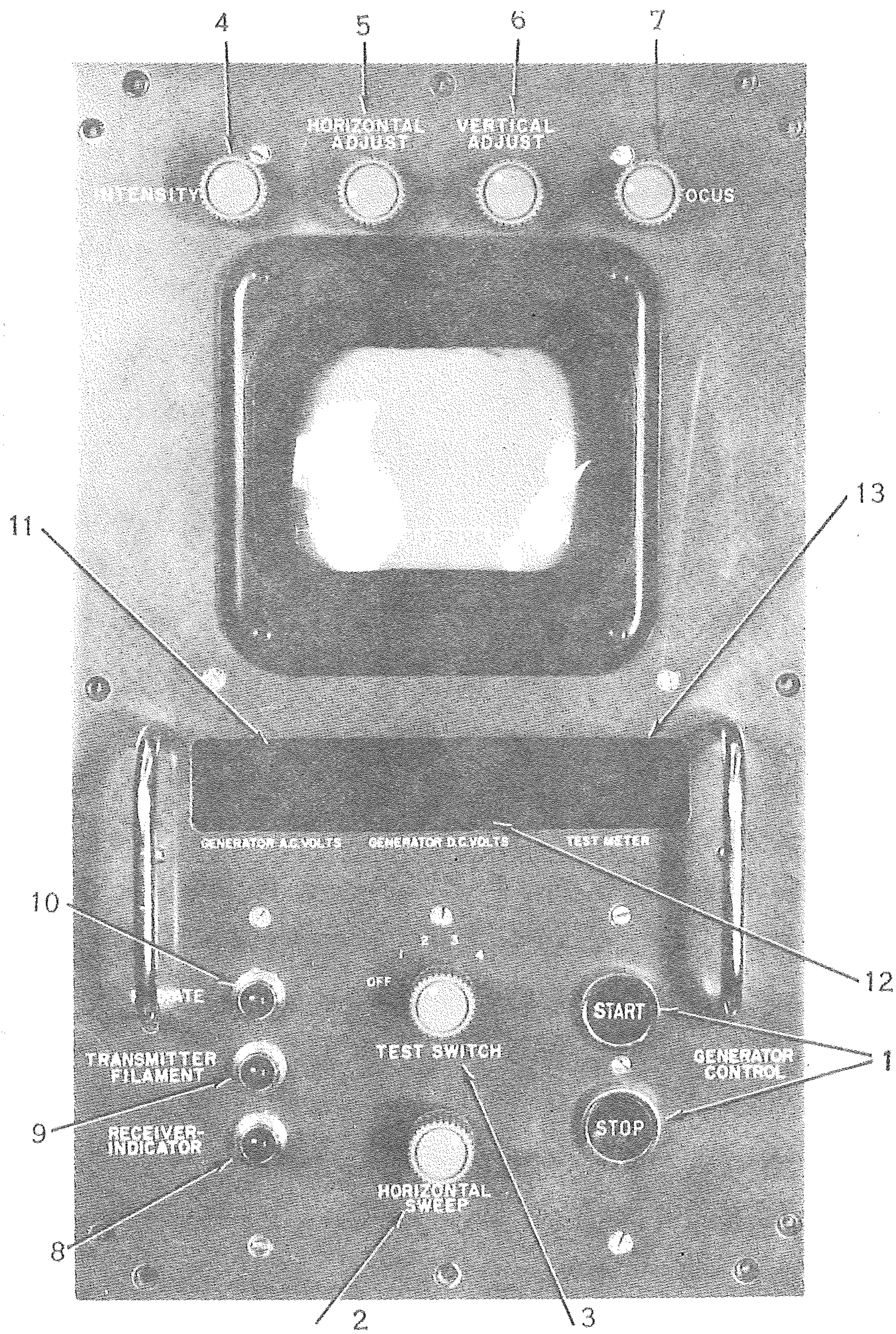


Figure 3. A-Scope Panel

The A-Scope Panel.

(1)	GENERATOR CONTROL START-STOP	Spring loaded holding type switch controls the starting and stopping of the motor generator.
(2)	HORIZONTAL SWEEP	Control knob for adjusting the length of the horizontal sweep on the A-scope.
(3)	TEST SWITCH	Five-position selector switch for testing driver amplifier voltages on the meter.
(4)	INTENSITY	Controls the brilliance of the sweep on the A-scope.
(5)	HORIZONTAL ADJUST	Control knob for adjusting the horizon horizontal centering of the sweep on the A-scope.
(6)	VERTICAL ADJUST	Control for adjusting the vertical centering of the sweep on the A-scope. This has been disconnected if the radar complies with Modification No. 10.
(7)	FOCUS	Control knob to adjust the focus of the image on the A-scope.
(8)	RECEIVER-INDICATOR	Lights when POWER switch on the local PPI panel is activated.
(9)	TRANSMITTER FILAMENT	Lights when TRANSMITTER FIL switch on the local PPI panel is activated.
(10)	RADIATE	Lights when the system is radiating.
(11)	GENERATOR A.C. VOLTS	Monitors a.c. input voltage.
(12)	GENERATOR D.C. VOLTS	Monitors d.c. input voltage.

(13)	TEST METER	Used with (3) to test the driver amplifier voltages.

The Local (5-inch) Plan Position Indicator Panel (fig. 4).

(1)	POWER ON-OFF	Toggle switch for turning on and off the primary power to all units.
(2)	TRANS FIL ON-OFF	Toggle switch to turn on and off all transmitter tube filaments, the receiver-indicator high voltage, the transmitter blower, and to energize the "bootstrap" circuit.
(3)	TRANS H.V. ON-OFF	Spring loaded, momentary contact toggle switch for applying high voltage to the transmitter and the remote 12-inch PPI scope.
(4)	ANTENNA POWER ON-OFF	Toggle switch for starting and stopping the azimuth rotation of the antenna.
(5)	RECEIVER GAIN	Control knob to regulate the receiver gain. Counterclockwise minimum gain, clockwise maximum gain.
(6)	KLYSTRON TUNING	Spring loaded, momentary contact toggle switch to tune the Klystron cavity.
(7)	ANTENNA MODE SELECTOR RHI AZI	Two-position selector switch; left for elevation scanning of the antenna, right for azimuth scanning.
(8)	PPI CENTERING HORIZONTAL	Screwdriver adjustment for horizontally centering the sweep on the Local and Remote PPI scopes.
(9)	PPI CENTERING VERTICAL	Screwdriver adjustment for vertically centering the sweep on the Local and Remote PPI scopes.

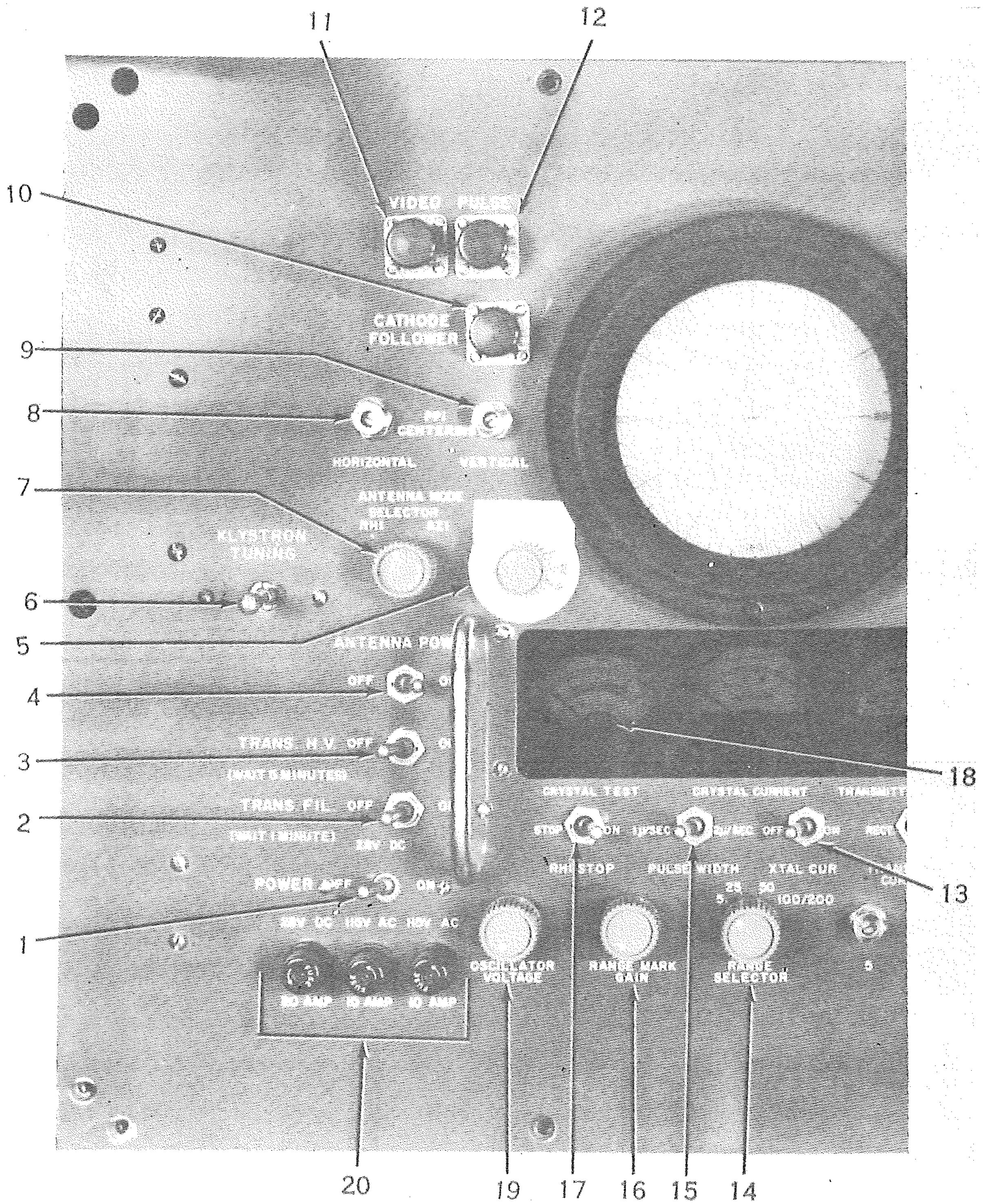


Figure 4. Left Section, Local Plan Position Indicator Panel

(10)	CATHODE FOLLOWER	Test jack. For technician's use only.
(11)	VIDEO	Test jack. For technician's use only.
(12)	PULSE	Test jack. For technician's use only.
(13)	XTAL CURRENT ON-OFF	Toggle switch for turning on or off the CRYSTAL CURRENT meter.
(14)	RANGE SELECTOR (5, 25, 50, 100/200)	Four-position selector switch to determine the range portrayed on the indicator scopes.
(15)	PULSE WIDTH (1 microsec. - 2 microsec.)	Toggle switch to select the pulse length (and pulse repetition frequency) to be used.
(16)	RANGE MARK GAIN	Control knob to regulate the brilliance and the amplitude (A-scope) of the range marks on all scopes.
(17)	RHI STOP ON-STOP	Toggle switch to stop the antenna at any desired angle of elevation.
(18)	CRYSTAL TEST	Meter used in conjunction with CRYSTAL CHECKER (21) to test the crystal mixer.
(19)	OSCILLATOR VOLTAGE	Control knob to adjust the repeller voltage on the Klystron.
(20)	20 AMP, 10 AMP, 10 AMP	Three fuses, one d.c. and two a.c.

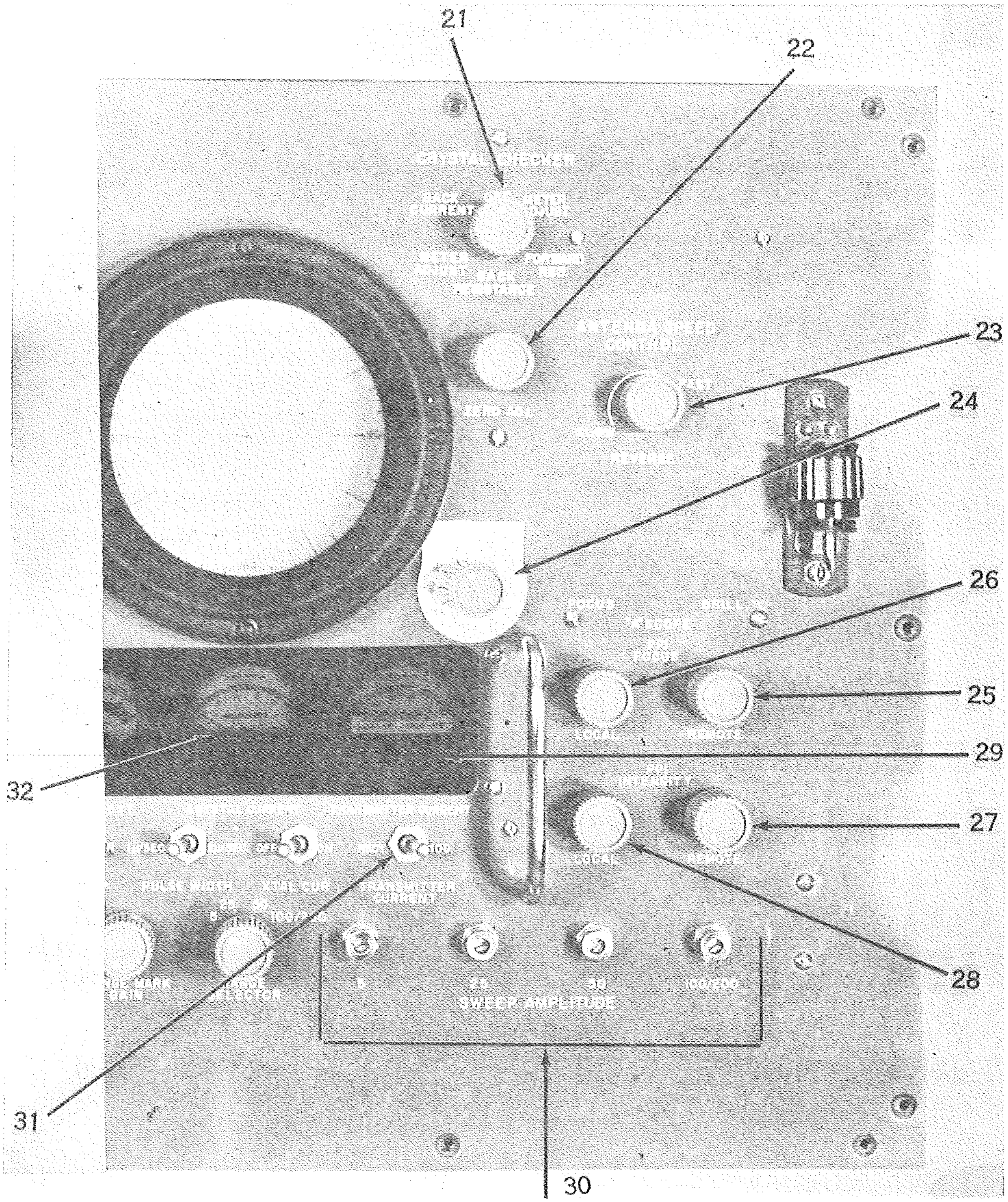


Figure 5. Right Section, Local Plan Position Indicator Panel

Items 21 through 32 pertain to figure 5.

(21)	CRYSTAL CHECKER	Six-position switch to enable the operator to test the crystal.
(22)	ZERO ADJ.	Control knob for "zero adjusting" the crystal test meter.
(23)	ANTENNA SPEED CONTROL (REVERSE-SLOW-FAST)	Control knob for changing the direction of antenna rotation and controlling azimuth speed.
(24)	VIDEO GAIN	Control knob for adjusting the amount of gain of the video signal. Counterclockwise minimum gain, clockwise maximum gain.
(25)	PPI FOCUS REMOTE	Control knob for focusing the image on the Remote PPI scope.
(26)	PPI FOCUS LOCAL	Control knob for focusing the image on the Local PPI scope.
(27)	PPI INTENSITY REMOTE	Control knob for controlling brilliance of the sweep on the Remote PPI (12-inch) scope. This is not required if Modification No. 10 has been effected.
(28)	PPI INTENSITY LOCAL	Control knob for adjusting the brilliance of the sweep on the Local PPI (5-inch) scope. This is not required if Modification No. 10 has been effected.
(29)	TRANSMITTER CURRENT	Meter measures the current of the Transmitter-Modulator circuitry.
(30)	SWEEP AMPLITUDE (5, 25, 50, 100/200)	Screwdriver adjustments for the sweep length of the respective five ranges.

(31)	TRANSMITTER CURRENT RECT MOD	Toggle switch for selecting readings of TRANSMITTER CURRENT meter.
(32)	CRYSTAL CURRENT	Meter measures the crystal current. Used in conjunction with (13).

The Remote (12-inch) Plan Position Indicator Panel (fig. 6).

(1)	DIMMER	Control to regulate illumination of the Remote PPI scope.

<u>STARTING PROCEDURE.</u> To place the WSR-3 radar set in operation proceed with the following steps:

(1) Make sure that the equipment is clear of personnel.

(2) Push GENERATOR CONTROL START button on A-scope panel.

(3) Observe meter readings on A-scope panel, GENERATOR A.C. VOLTS should read 112 to 119 volts. GENERATOR D.C. VOLTS should read 28 volts $\pm 10\%$.

(4) Turn A-scope and PPI INTENSITY controls counterclockwise.

(5) Energize POWER ON-OFF switch on PPI panel. RECEIVER-INDICATOR light on A-Scope panel should be illuminated.

(6) Refer again to step 3.

(7) Wait approximately 1 minute after step 5, then energize TRANSMITTER FILAMENT switch. TRANSMITTER FILAMENT light should be illuminated.

(8) Observe that the CRYSTAL CHECKER control is off. Throw XTAL CUR switch on. Observe CRYSTAL CURRENT meter; the meter should indicate between 0.4 and 0.6 mA. To peak crystal current, adjust OSCILLATOR VOLTAGE control for the highest of the two or three peaks which are indicated on the CRYSTAL CURRENT meter.

(9) Switch ANTENNA MODE SELECTOR to AZI position. (Check that antenna is unobstructed.)

<u>Caution:</u> Do not operate the radar when antenna rotation is sluggish due to extremely cold temperatures.

(10) Turn ANTENNA POWER on.

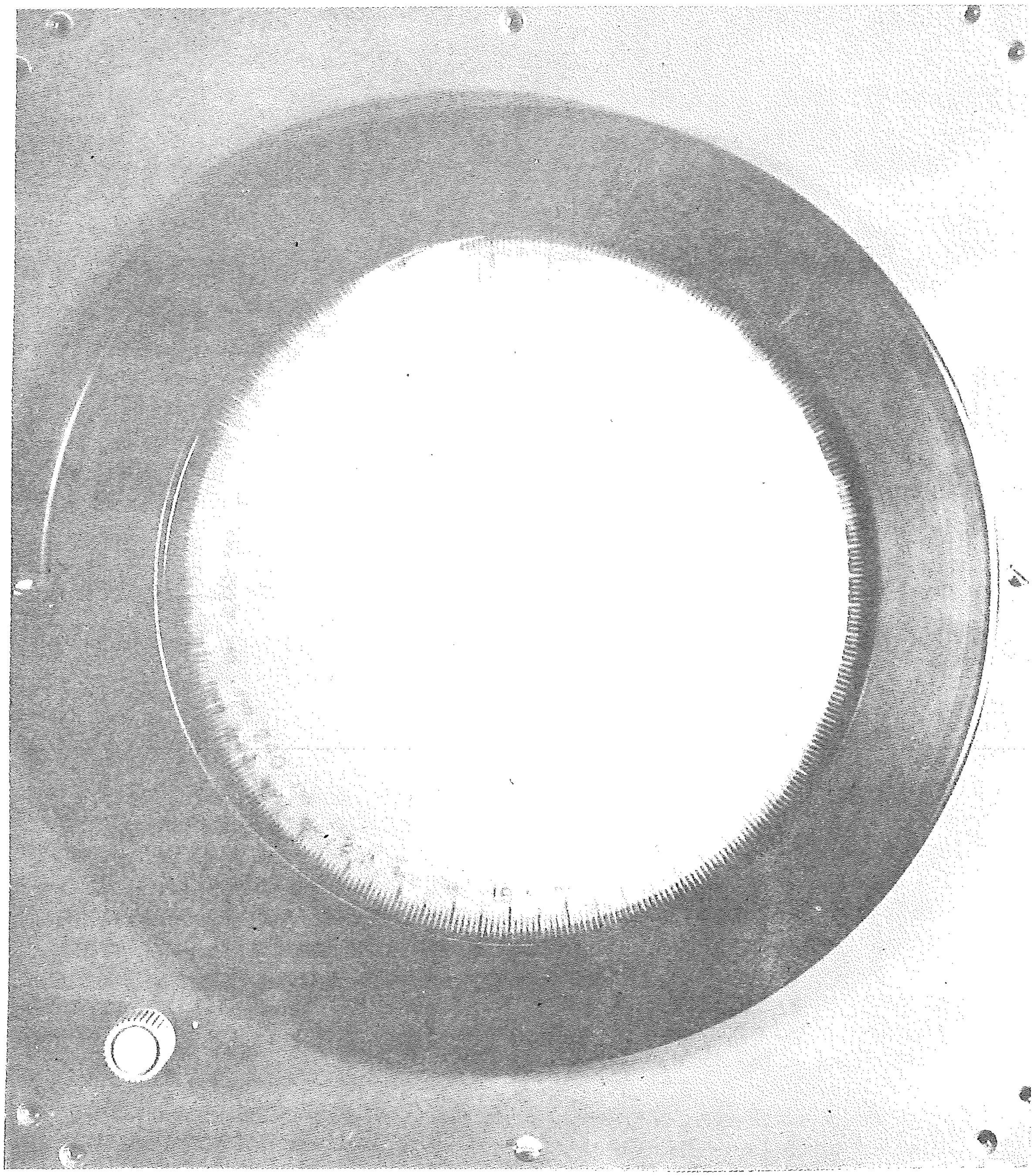


Figure 6. Remote Plan Position Indicator Panel

(11) Turn local PPI INTENSITY and A-SCOPE INTENSITY control clockwise until a sweep line is visible with no video or receiver gain. Advance VIDEO GAIN and RECEIVER GAIN to maximum clockwise position. Center sweep on A and PPI scopes by adjusting the VERTICAL and HORIZONTAL controls on their respective panels. The FOCUS controls on the A and PPI scope panels should be adjusted until the sweep line is sharply defined.

<u>Note:</u> No sweep will appear on the remote PPI until after step 14 is accomplished.

(12) Position RANGE SELECTOR switch to each range position. Adjust the respective SWEEP AMPLITUDE control until the PPI sweep line reaches the outer edge of the scope tube.

(13) Rotate ANTENNA SPEED CONTROL switch and check for proper speed and reversing.

(14) When 5 minutes have elapsed after turning TRANSMITTER FILAMENT on (step 7), throw TRANSMITTER H.V. switch to ON. The RADIATE light on the A-scope panel should be illuminated.

(15) Observe TRANSMITTER CURRENT meter. It should indicate roughly 7.2 with TRANS CUR switch in MOD position and 10.0 when thrown to RECT position.

(16) Rotate voltage TEST SWITCH on A-scope panel and observe readings on the TEST METER. The meter should indicate in the normal (shaded) area in all positions.

(17) Turn REMOTE INTENSITY control clockwise until a sweep line is visible on the remote PPI scope. Adjust the REMOTE FOCUS control until the sweep line is sharply defined.

(18) Switch ANTENNA MODE SELECTOR to RHI.

(19) Throw RHI-STOP switch to the ON position.

(20) After one cycle, and with RHI sweep on the remote PPI approaching zero elevation, turn ANTENNA SELECTOR switch to AZI and check remote PPI sweep for automatic leveling.

(21) Again adjust OSCILLATOR VOLTAGE for highest peak (step 8).

(22) Adjust RECEIVER GAIN for approximately one-fourth of "grass" on the A-scope.

(23) Adjust RANGE MARK GAIN until range marks appear on the scopes. On the A-scope the range marks will be represented by vertical sharp marks evenly spaced along the sweep line.

(24) Adjust VIDEO GAIN to show its effect on the scopes.

(25) With antenna rotating (RHI-AZI control in AZI position) at 0° level, (RANGE SELECTOR to 25) pick out distant echo on both PPI scopes.

(26) Stop rotation on distant echo by turning the ANTENNA POWER to OFF.

(27) Adjust KLYSTRON TUNING for highest peak on distant echo as seen on the A-scope.

(28) Again adjust OSCILLATOR VOLTAGE control for highest peak or CRYSTAL CURRENT meter. (Steps 8 and 21.)

(29) Repeat step 25 on more distant echo if one is seen, and follow through with steps 26, 27 and 28.

STOPPING PROCEDURE. To turn the WSR-3 radar off the following sequence should be followed:

(1) Turn ANTENNA POWER switch to OFF.

(2) Turn TRANSMITTER FILAMENT switch to OFF.

(3) Turn POWER switch to OFF.

(4) Push GENERATOR CONTROL switch to OFF position.

Radar system is now completely de-energized.

Caution: Stopping procedure should be followed in sequence set forth. Failure to follow steps may result in the damaging of the magnetron oscillator tube or the equipment in general.

Standby Operation. It may be desirable to operate the equipment in a standby condition. This eliminates the usual warmup period before each observation. In this case, the transmitter high voltage may be removed by momentarily turning off the TRANSMITTER FILAMENT switch, then immediately switching it back on again. The radar remains heated and ready for operation by switching on TRANSMITTER HIGH VOLTAGE.

Scopes and Their Operation. The WSR-3 radar uses three scopes for the display of echoes; a 5-inch A-scope, a 5-inch PPI scope, and a 12-inch Remote PPI scope.

A-Scope. The 5-inch A-scope is used to indicate amplitude versus range as presented by a target in the radar beam. The amplitude of the echo display on the scope is an indication of the reflectivity of the target. The A-scope is also used to tune the receiver and the transmitter, as outlined in steps 25 through 28 of the starting procedures.

PPI Scopes. The 5-inch and the 12-inch PPI scopes present a maplike presentation on a horizontal plane of all targets within the radar's range capable of being detected. The sweep on the scope follows the rotation (scan) of the antenna to indicate azimuth, while the distance from the start of the sweep to the indicated echo on the scope determines the range of the target. A choice of 5, 25, 50, 100/200 miles range presentation is available.

Ranging. To determine the range of an observed target, the RANGE MARKS GAIN is turned in a clockwise direction until the concentric circles representing the range marks are legible on the PPI scope. On the A-scope the range marks will be represented by vertical sharp marks evenly spaced along the sweep line. The spacing between the concentric circles (range marks) on the PPI scopes or the vertical marks as viewed on the A-scope represent a unit of distance calibrated in nautical miles. For example: The span or distance represented on the 25-mile range between any two circles on PPI scopes, or vertical marks on the A-scope, represents a distance of 5 nautical miles.

Range Marks Calibration

Range Switch Settings (miles)	Number of Rings or Marks	Distance Between Marks (miles)
5	5	1
25	5	5
50	5	10
100	5	20
200	9	20

ALL RANGES ARE IN NAUTICAL MILES

It may be noted in the operation of the equipment that on short ranges, such as the 25- and 50-mile ranges, the range marks near the center of the tube may be covered by strong ground clutter. The range marks may be easily discerned by momentarily turning the RECEIVER GAIN to minimum gain.

RHI Scanning. In the AZIMUTH position of the ANTENNA MODE SELECTOR switch, a plan position type of display is produced (on the PPI scopes) as the antenna revolves continuously. The vertical structure of a particular storm area may be studied by stopping the antenna on the center of the storm (switching the ANTENNA POWER switch to OFF). The ANTENNA MODE SELECTOR is then switched to the RHI position (the RHI STOP switch is left in the ON position). The antenna will scan vertically from -2° to approximately +50° continuously. At the time the sweep will scan accordingly on the RHI scale provided on the remote PPI display (fig. 6). This RHI display will represent the vertical structure of the precipitation area. The angular elevation, as read from the RHI scale, along with the range of the echo, as determined from previous horizontal PPI scans and A-scope displays, can then be used to compute the actual height, in feet, of the echo by the use of appropriate tables.

The vertical scanning of the antenna may be stopped and the antenna set at any desired elevation angle by actuating the RHI STOP switch to its STOP position. The ANTENNA MODE SELECTOR then is switched to AZIMUTH position and the radar antenna is revolved in azimuth at that particular angle. This latter feature is particularly useful in determining those echoes or targets having the highest vertical structure. Starting with a high elevation angle, the antenna is lowered several degrees at a time with each revolution of the antenna, by momentarily switching the RHI STOP switch to the ON position, as the antenna searches in azimuth. The first discernible echo will have the greatest vertical structure, providing the range distance to other echoes is compatible. If the actual height in feet of this first discernible echo is desired, it will be necessary to stop the rotation of the antenna on the azimuth of this echo, and by switching the ANTENNA MODE SELECTOR switch to the RHI position and the RHI STOP switch to the ON position, the height can be determined from the RHI DISPLAY on the 12-inch PPI scope.

With the ANTENNA MODE SELECTOR switch in the AZIMUTH position, when the RHI STOP switch is turned to the ON position, the antenna will always return to the zero angle elevation position and "lock-in" until the ANTENNA MODE SELECTOR switch is again changed.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

OPERATIONAL PROCEDURES FOR ARTC TYPE RADAR

1. Upon approaching a radar console, check the indicator lights and controls to be certain of the following: (Note: If lights are not available check the following with Duty Eltech.)

   a. Check the lights to see if receiver is on amplitron or magnetron. The lights on the right side of the high voltage switch will indicate amplitron or magnetron. First check the two channel light indicators to see if the system is operating on channel A or B. Then look at the same channel light in the high voltage section. If this light is steady the transmitter is using the amplitron (4000 kW transmitted power). If the light is flashing the transmitter is using only the magnetron (400 kW transmitted power). If the amplitron is not being used, point the fact out to one of the technicians and request that the amplitron be turned on if possible. If the amplitron cannot be turned on, make a note on the base map that this particular system is on MAG.

   b. Check lights to see if receiver is on linear or circular polarization (see number 4 below).

   c. Turn background control knob completely counterclockwise.

   d. MTI-normal control turned fully clockwise to MTI position.

   e. Beacon ON and fully clockwise.

   f. Cursor OFF.

   g. ADF OFF.

   h. Map video OFF.

   i. Range control fully cw to 200-mile position. Use of range marks is optional.

   j. Place decenter switch in decenter position.

k. Turn MTI video gain to OFF position (full ccw) and bring sweep intensity up until sweep is just barely visible. Turn both MTI and normal video gains to full ON position (full cw).

2. Place the appropriate overlay on the scope face with the north mark offset to compensate for magnetic declination. By means of the sweep origin controls place the sweep origin directly under the center of the scope overlay, being careful to avoid parallax error (line up the sweep origin on face of scope and the center mark of the scope overlay with the reflection of the eye on the scope).

3. Trace the echoes depicted on the MTI channel, then switch to the normal channel and see if any more echoes are depicted, tracing these also if they occur.

4. If the receiver is on CP, outline the echoes depicted on both MTI and normal, then call the Facilities Coordination Officer and ask if it is possible to switch to linear long enough to trace the echoes (approximately 5 minutes). Cover STC in the same manner as CP if you think significant echoes are oblitered by STC. If STC or CP is on, make a note on the base map that this particular system is on STC or CP.

5. Repeat this procedure at each console using the appropriate scope overlay.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

AIR ROUTE TRAFFIC CONTROL RADARS

ARSR-RADAR LOCATION	MONITORING LOCATION
Albuquerque, N. Mex.	ARTCC Albuquerque, N. Mex.
Amarillo, Tex.	ARTCC Albuquerque, N. Mex.
Ashton, Idaho	ARTCC Salt Lake City, Utah
Battle Mountain, Nev.	ARTCC Salt Lake City, Utah
Boise, Idaho	ARTCC Salt Lake City, Utah
Boron, Calif.	ARTCC Palmdale, Calif.
Cedar City, Utah	ARTCC Palmdale, Calif. and ARTCC Salt Lake City, Utah
El Paso, Tex.	ARTCC Albuquerque, N. Mex.
Klamath Falls, Oreg.	ARTCC Auburn, Wash.
Las Vegas, Nev.	ARTCC Palmdale, Calif.
Los Angeles, Calif.	ARTCC Palmdale, Calif.
Lovell, Wyo.	ARTCC Salt Lake City, Utah
Mesa Rica, N. Mex.	ARTCC Albuquerque, N. Mex.
Mt. Laguna, Calif.	ARTCC Palmdale, Calif.
Paso Robles, Calif.	ARTCC Palmdale, Calif.
Phoenix, Ariz.	ARTCC Albuquerque, N. Mex.
Pico del Este, P.R.	ARTCC San Juan, P.R.

Continued.

ARSR-RADAR LOCATION	MONITORING LOCATION
Rock Springs, Wyo.	ARTCC Salt Lake City, Utah
Salem, Oreg.	ARTCC Auburn, Wash.
Salt Lake City, Utah	ARTCC Salt Lake City, Utah
San Pedro, Calif.	ARTCC Palmdale, Calif.
Seattle, Wash.	ARTCC Auburn, Wash.
Silver City, N. Mex.	ARTCC Albuquerque, N. Mex.
Spokane, Wash.	ARTCC Auburn, Wash.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

OPERATING INSTRUCTIONS FOR VE-1 REPEATER

General. The remote repeater, Model VE-1, is a plan position indicator. Its purpose is to duplicate, at remote points, the data shown on the plan position indicator of the master radar. The unit is designed to operate on ranges independent of the ranges of the console.

Operating Controls and Their Functions. The controls normally used in operating the repeater are contained on a panel located on the front of the unit. (fig. 1)

The VE-1 Repeater Operating Controls.

(1)	DIAL DIMMER	Dims the dial lights.
(2)	RANGE	Small opening through which the range at which the equipment is operating can be read.
(3)	VIDEO GAIN	Controls gain of the video signal being fed into the repeater scope.
(4)	FINE INTENSITY	Adjusts intensity of visible sweep on scope.
(5)	RANGE	Selects range of 4, 20, 80, or 200 nmi.
(6)	FOCUS	Used to adjust the focus of the image on the scope for the sharpest presentation.
(7)	CENTER EXPAND	With this switch turned to ON position, the sweep circuit will not start at the center of the tube, but at a point 1/2" from it. The start of the trace will still represent zero range, and neither range nor bearing accuracy will be affected.

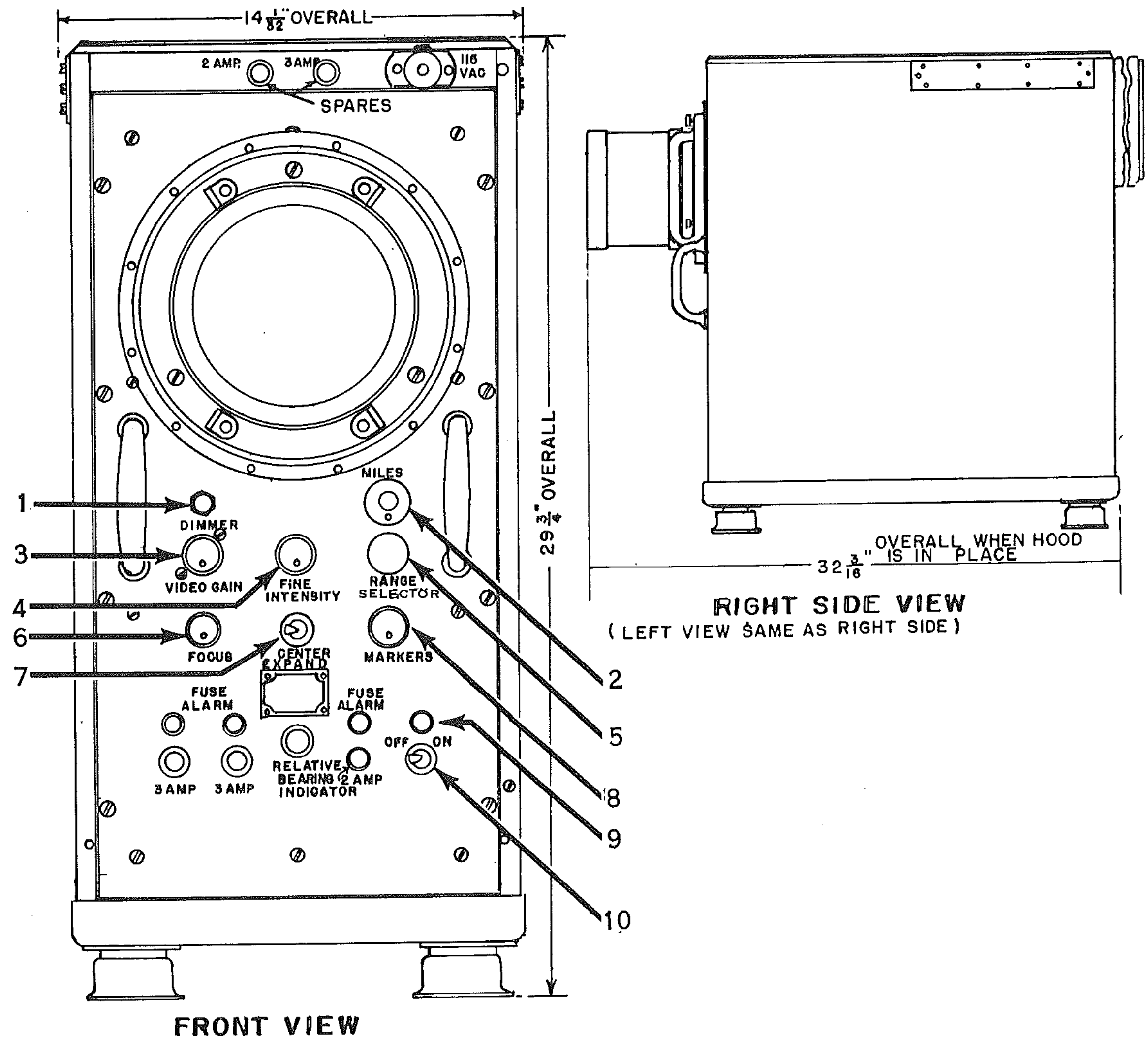


Figure 1. Model VE-1 Remote Repeater

(8)	MARKERS	Places four bright dots along the sweep line approximately equally spaced.
(9)	ON-OFF	Power switch for repeater.
(10)	ON-OFF	Indicator shows that power is on.

Starting Procedure. To place the repeater in operation:

(1) Turn ON-OFF switch to ON position. Allow the equipment to warm up for about 3 minutes.

(2) Adjust the RANGE switch to the 200-mile range.

(3) Adjust FINE INTENSITY and FOCUS controls alternately so that sweep is barely visible.

(4) Turn the VIDEO GAIN control in a clockwise direction until echoes appear on the face of the tube.

(5) To make certain that the sweep starts in the center of the tube, the face of the tube should be observed carefully while the sweep is rotating and the CENTER EXPAND switch is in the OFF position. If not, the electronics technician should be notified.

(6) Turn up the MARKERS control slowly until four bright spots appear along the sweep line on the face of the tube. These will be approximately equally spaced. If the radar antenna is rotating, these dots will trace out four circles around the face of the tube, concentric with the center of the tube face. Throw the RANGE switch to the other three ranges and check to see if the dots appear on these three ranges. The intensity of these dots can be adjusted by the MARKERS control and should be adjusted so that the lines they trace, when the antenna is rotating, are as narrow and clear as possible.

(7) Adjust the DIAL DIMMER control until the illumination from the lights around the bezel permits the image on the tube face to be seen clearly.

(8) To obtain the proper setting of the FINE INTENSITY control on any of the four ranges, the following procedure should be used: First, turn the VIDEO GAIN control completely OFF (counterclockwise). Then turn the FINE INTENSITY control OFF (counterclockwise). Turn the INTENSITY control clockwise until a light fuzzy, "grassy" picture appears on the face of the tube. This picture should be turned up only high enough to be barely visible. Turn the VIDEO GAIN control clockwise until signals appear in sharp focus and with relatively bright illumination. The INTENSITY control should not again be adjusted. After a range has been set in this manner, the operation will be incorrect if the INTENSITY control is turned. Signals will be seen if the INTENSITY control is turned, but the weaker signals may be lost. Echoes may be seen on all ranges without readjustment of the INTENSITY or VIDEO GAIN controls. But, for maximum effectiveness, the proper setting should be obtained each time the RANGE switch is moved. This insures that the INTENSITY and VIDEO control settings will show up the weaker echoes.

(9) The CENTER EXPAND switch should be adjusted for proper operation. Adjust the RANGE switch for operation on the 4-mile range, and set the VIDEO GAIN and INTENSITY controls for this range. Turn the CENTER EXPAND switch to the ON position. The sweep circuit will not start at the center of the tube, but at a point about one-half inch from it. This spreads out the local echoes so that individual signals may be distinguished.

Operating Procedures. When the repeater scope is used to provide additional PPI presentations for forecasting, pilot briefing, etc., the range, gain, and intensity controls should be adjusted to meet the individual need.

To Determine Range on the PPI. When the MARKERS switch is turned up, four range marker rings will appear, if the antenna is rotating. If the antenna is "search-lighting," four range marker dots will appear. On the 4-mile range, these markers are 1 mile apart. On the 20-mile range they are 5 miles apart, and so on.

To Determine Bearing. Read the azimuth ring around the rim of the PPI scope.

Fuse Indicators. Small amber lights will be noticed directly above the fuses. These lamps normally do not light, except to indicate a blown fuse. When one of these lights glow, it is a sign that the fuse below it has been blown. Replace the blown fuse with another. If the fuse was blown by something of a transient nature, the light will be out when the fuse is replaced. However, if it burns again, it means that a second fuse has blown and that trouble may have developed requiring repair inside the equipment. In this case, the electronics technician should be notified.

Stopping Procedure. Turn ON-OFF switch to OFF position.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

OPERATING INSTRUCTIONS FOR VD-2 REPEATER

General. The repeater, Model VD-2, is a remote indicator with a 7-inch PPI scope. It is designed for use with any type of radar equipment capable of presenting PPI information. The intensity of the echoes presented on the VD-2 repeater scope are dependent upon the master radar receiver gain and video gain control settings. The unit is designed to operate on ranges independent of the ranges of the console. With the equipment operating satisfactorily, the azimuth bearings indicated by the VD-2 repeater will agree with $\pm 2.2°$ of those indicated by the master radar set.

When operating on the 200-mile range, a ring somewhat resembling a range ring may appear at or beyond a range of 80 miles. This will occur if the master radar has a repeater rate appreciably greater than 300 pulses per second. The condition is normal, and does not indicate a fault in the equipment.

Operating Controls. The controls normally used in operating the VD-2 repeater are contained on a panel located on the front of the cabinet housing the device (fig. 1).

The VD-2 Repeater Operating Controls.

(1)	CENTER EXPAND	When this control is turned fully clockwise, there will be a blank space with a diameter of approximately 1 inch in the center of the pattern. The start of the trace will still represent zero range however, and neither range nor bearing accuracy will be affected.
(2)	INTENSITY	Adjusts PPI intensity.
(3)	RANGE MARKS	Adjusts the intensity of the range marks.

1. OPERATING CONTROLS

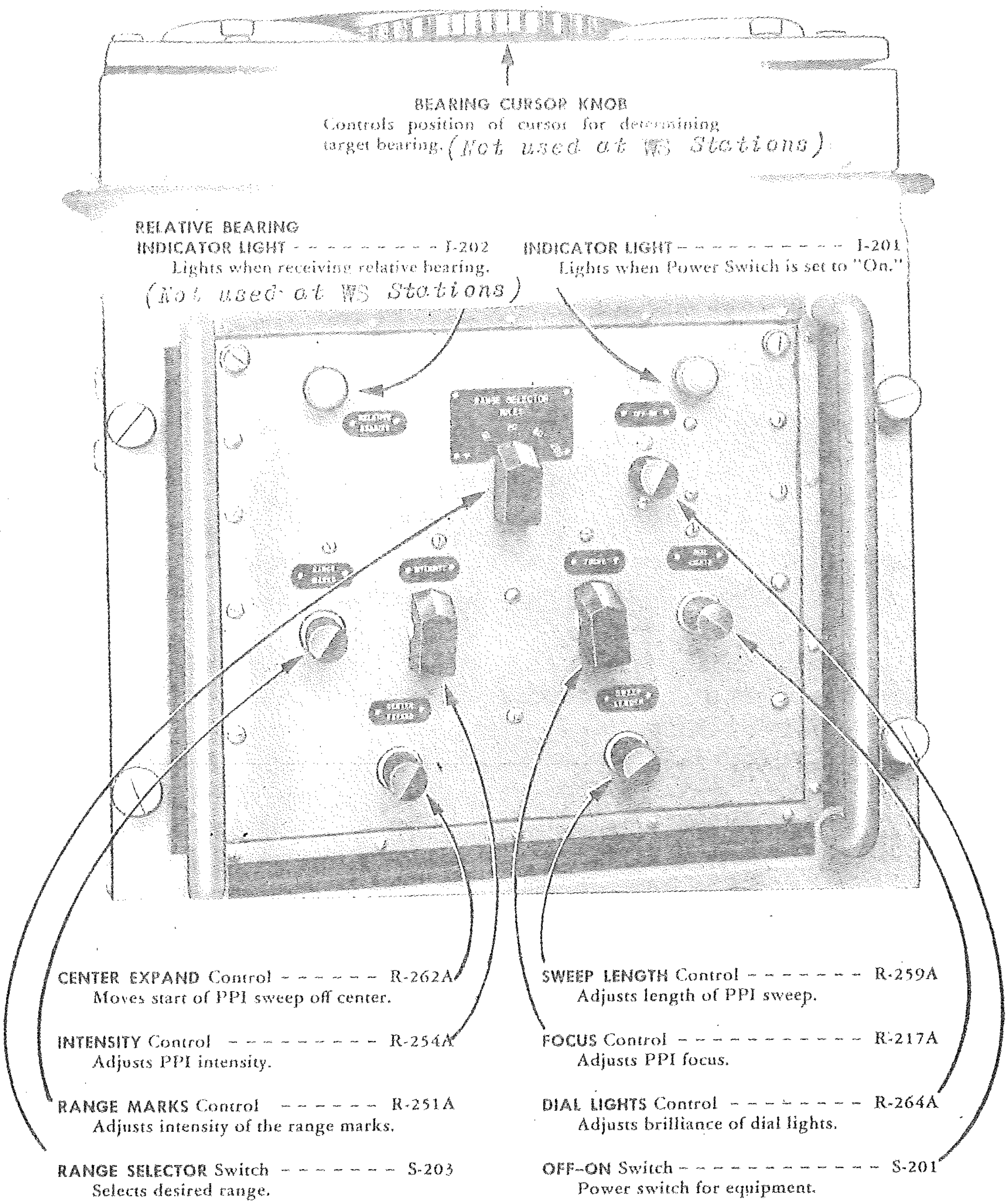
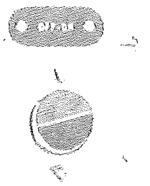
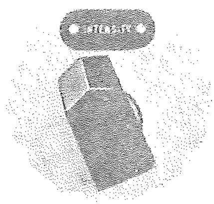


Figure 1. Model VD-2 Repeater Operating Controls

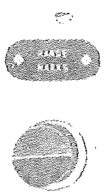
3. STARTING THE EQUIPMENT



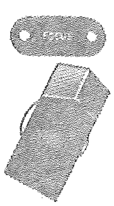
1—Turn the OFF–ON Switch to "On" and select an operating master radar with the Selector Switch.



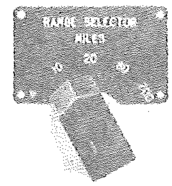
2—After the filaments have heated, advance the INTENSITY Control until a sweep appears on the PPI.



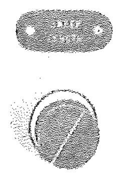
3—Adjust the RANGE MARKS Control for the desired marker intensity.



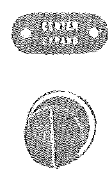
4—Adjust the FOCUS Control for optimum focus of marks and targets.



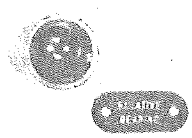
5—Set the RANGE SELECTOR Switch to the desired range.



6—Adjust the SWEEP LENGTH Control to place the fourth mark at the outer edge of the PPI.

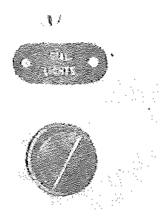


7—Adjust the CENTER EXPAND Control until the sweep makes a small circle or dot at the center of the PPI, as desired.



If RELATIVE BEARING Lamp is lit, master radar is transmitting relative bearing.

(Not used at WS Stations)



8—Adjust the DIAL LIGHTS Control for the desired brilliance of the bearing dial.

Figure 2. Model VD-2 Repeater Starting Procedure

(4)	RANGE SELECTOR	Switch to desired range. Five ranges are provided: 4, 10, 20, 80, and 200 nmi.
(5)	SWEEP LENGTH	Adjusts the length of the sweep on the PPI.
(6)	FOCUS	Focus the PPI image for the sharpest presentation.
(7)	DIAL LIGHTS	Control which adjusts brilliance of dial lights.
(8)	OFF-ON	Power switch for equipment.

Starting Procedure. The proper settings for the various operating controls at the time the equipment is turned on are shown in figure 2.

Operating Procedures. When the repeater scope is used to provide additional PPI presentations for forecasting, pilot briefing, etc., the range and intensity controls should be adjusted to meet the individual need.

To Determine Range. Turn up the RANGE MARKS control until the range marks are visible. If the antenna is rotating, four marker rings will appear. If the antenna is "search-lighting," four range marker dots will be visible. On the 4-mile range these markers are 1 mile apart. On the 20-mile range they are 5 miles apart, and so on. Adjust the RANGE SELECTOR switch to the lowest possible setting on which the target may be seen on the screen. Estimate the distance to the target, by comparing its position with the nearest range marker. For example, if operating on the 20-mile range, and the target is half-way between the second and third rings, the range will be read as 12.5 miles from the radar.

To Determine Bearing. Read the azimuth ring around rim of the PPI scope.

Stopping Procedure. Turn OFF-ON switch to OFF position.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

OPERATION OF ALDEN CONTINUOUS FLAT COPY SCANNER

Normal Operation (240 scans/minute).

1. Turn power switch on (located at back edge, left side of scanner).

2. Turn floodlight polarity switch to either "on" position. This switch should be reversed every 8 hours or quality of transmission will deteriorate.

3. Scan speed lever should be in 240-scans/minute position. This lever is located at left side of roller feed assembly. If this control is in the 120-scan position, see section on changing scan speed.

4. Helix sweep speed switch should be in 240-scan position. This switch is located behind the bottom front panel. Snap out the top of the panel to expose the switch.

5. Check the lights at the top of the modulator unit to make certain a carrier frequency of 2,400 is being used. If the 1,800 light is on, push the switch between the lights to switch to 2,400.

6. Place scans/inch lever in 96-scans-per-inch position to transmit maps.

7. Check the various indicator lights on the front panel to make certain the equipment is functioning properly.

8. Push down on the three switches located under the scanner table surface simultaneously. These switches are to light the floodlamps. Make certain all the floodlamps are lit.

9. Pull out the output signal monitor scope.

10. Put the feed lift control at the top of the roller feed assembly in the horizontal position. This will lift the roller feed assembly and enable you to insert the copy to be transmitted.

11. Insert the copy to be transmitted face down under the roller feed assembly. Make certain that all data to be transmitted will feed over the open portion of the scanner table and be exposed to the floodlights; otherwise, the data will not be transmitted.

12. Pull out the feed lift control and allow it to return to the vertical position.

13. Check the signal-to-background ratio on the output signal monitor scope. It should be at least 4 to 1 and preferably 6 to 1. If it is not in this range, reset the background and black level controls in the modulator unit until the desired ratio is achieved. Once the signal background ratio has been established, do not change it from one transmission to another. Keeping our transmitting levels the same will enable the receiving stations to set their recorders up for our level and leave them alone. If we change levels frequently, too dark or too light copy will result at the receiving end.

14. Push in and hold the transmit start button at the left side of the roller feed assembly. Hold this button in until the start signal is observed on the output signal monitor scope and the DB meter. While the copy is being transmitted, the "on transmit" light in the signal control unit should be on.

15. When the copy has finished transmitting, push the transmit stop button at the left side of the roller feed assembly, holding button down for 5 seconds. Observe the "on transmit" light again to make certain that it goes out.

16. Pull out the feed lift control and place it in a horizontal position. Remove the transmitted copy from the rear of the scanner table and file.

<u>Changing Speed of Transmission</u> (From 240 scans/minute to 120 scans/minute).

1. Move the scan speed control to the 120-scan position.

2. Open the top of the bottom front panel and switch the helix sweep speed control to 120-scan position.

3. In the modulator unit push the switch between the lights and change carrier frequency from 2,400 to 1,800.

4. Follow Steps 6 to 16 of the normal operation section.

5. To switch from 120 scans/minute to 240 scans/minute reverse the operations in Steps 1 to 3.

FILE WITH SECTION II, FACILITIES, EQUIPMENT OPERATION AND MAINTENANCE

RADAR HAZARDS

"Radar Hazards" published by the National Safety Council is the text of this issue. The copy along with this cover page attached should be placed in Section II, Part C, of the Weather Radar Manual.

SECTION III
OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

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OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

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FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

OPERATING INSTRUCTIONS FOR THE VIDEO INTEGRATOR AND PROCESSOR

I. INTRODUCTION.

The Video Integrator and Processor (VIP) is an adjunct of the WSR-57 radar system. It has been developed to meet both present and anticipated requirements for continuous quantitative data output for (1) console presentation, (2) dissemination by remoting systems such as the WBRR-68, (3) photographic data recording, and (4) further processing using computer techniques. The VIP automatically processes the output of the radar's logarithmic receiver to produce up to six levels of intensity data corresponding to pre-selected categories of estimated rainfall rates. These levels may be displayed individually or simultaneously on the radarscope. This will permit the constant monitoring of echo intensities, within these categories, with each rotation of the antenna.

II. MODES OF OPERATION.

There are two basic modes of operation designed into the VIP: (1) the contoured log (C-log) and (2) log. The C-log mode can be used to present up to six levels of intensity according to table 1.

The log mode presents the output of the logarithmic receiver without contours. This mode may be used on all ranges; however, the C-log is presently limited to 125 nmi or less.

Whenever the linear receiver of the radar is used, the VIP does not affect the scope displays in any way.

TABLE 1

Level	Display#	Rainfall Category	Rainfall Rate (in./hr., lower level)	LOG Z	Pr*
1	gray	light	<0.1		<-99.5
2	white	moderate	0.1-0.5	3.0	-88.0
3	black	heavy	0.5-1.0	4.1	-77.0
4	gray	very heavy	1.0-2.0	4.6	-72.0
5	white	intense	2.0-5.0	5.0	-67.5
6	black	extreme	>5.0	5.7	-61.0

#Refers to radar PPI. White and black are reversed on WBRR.
*Equivalent received power using the LIN receiver. The actual signal generator values used to set up the VIP thresholds are 2.5 dB lower than these values, for example -90.5 dBm rather than -88 dBm in the case of level 2.

III. VIP CONTROL FUNCTIONS.

The VIP is designed to be operated full time. The OFF-ON switch is located on the back of the cabinet. In order for the VIP calibration to be valid, the radar must be operated in the log receiver mode at 3 rpm, in long pulse, with STC OFF. The mode of operation is selected by using either the log or C-log push button switch on the right side of the VIP cabinet face. In the C-log mode, combinations of levels may be selected by using the level selector push button switches on the left of the cabinet face. Each of these six switches has an indicator light just above the switch. These lights are energized as the signal passes each level and remains on for 20 seconds (one rotation of the antenna at 3 rpm). A quick glance at these lights near the end of each rotation will reveal the highest level signal for that rotation of the antenna.

IV. OPERATIONAL REQUIREMENTS.

Camera repeater scopes and WBRR transmitters should normally present contoured displays. This means that the radar must be operated in long pulse, and the VIP must be in C-log mode with all six levels selected for display. The radar STC must be turned off or disabled since range normalization is provided by the A-10 board which should have been installed.* The radar antenna must be allowed to rotate at 3 rpm, with tilt adjusted for precipitation detection over the optimum range. The rotation speed should be checked and adjusted during the periodical calibration check, and more frequently if necessary. If this "normal" operation is interrupted for lengthy periods, because of equipment malfunction or for any other reason, appropriate notations should be included on WBRR and camera scope displays. Whenever the normal operation is interrupted briefly, such as for echo top measurement, notations are not necessary. In either case, the normal operation should be resumed as soon as possible.

*All levels except level 1 are range normalized. Level 1 is not range normalized so that all detectable light precipitation will be displayed as level 1.

V. OBSERVATION TECHNIQUES.

The VIP facilitates the recording of radar reports (SD) and narrative reports because it displays on a single sweep a contoured picture which, if constructed by attenuators and grease pencil, would be several minutes in the making. The following observational procedure is suggested:

After determining that the radar is delivering standard performance, set the radar console PPI to 250-nmi range (C-log cannot be used for this display)* but do not interrupt C-log VIP mode service to remote displays. If there are echoes beyond 125 nmi, locate and record the areas, lines, and cells as necessary on this range setting. Switch then to the shortest range that will display all the echoes within 125 nmi, and switch the main PPI to the VIP C-log display. Manipulation of the level selector switches will allow determination of maximum intensities and characteristic intensities as reported in SD's and narrative summaries. Note that the normal antenna rotation is not interrupted, and that remote displays can be served with C-log VIP mode while the main PPI is adjusted to the 250-nmi range. It will be necessary to stop the normal antenna rotation in order to determine vertical configuration. This should be done as necessary, but on a scheduled basis as much as possible. Top measurements may be made within the lin receiver, or with the VIP in C-log mode.

*A modification is being developed to permit C-log VIP operation on 250-nmi range; contours would only appear to 125 nmi, and normal echo presentation beyond 125 nmi.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

ECHO INTENSITY DETERMINATION

WSR-57 stations not equipped with the Video Integrator and Processor (VIP) will determine echo intensity and theoretical rainfall rates by a method that utilizes their precision attenuator capability. The Rainfall Rate-Echo Intensity Chart (fig. 2) was designed to facilitate these computations. The following procedure is suggested:

(1) Use attenuators and A-scope or R-scope display.

(2) Be sure that the LIN IF receiver gain control and A-scope video amplitude are set according to instructions in the Weather Radar Manual, part C, section II, "Operating Instructions for WSR-57 Radars."

(3) With the antenna stopped on the target, increase the attenuator setting until the top of the echo reaches the middle reference line on the A-scope overlay (fig. 1).

(4) Add the deviation, in dB, of the peak transmitted power from 410 kW, if the actual transmitted power is less than 410 kW. (Subtract if it is greater than 410 kW.)

(5) Note the corrected dB attenuation value obtained by steps 3 and 4.

(6) Determine the range to the target in the usual manner.

(7) Determine the theoretical rainfall rate and echo intensity from figure 2.

<u>NOTE</u>: This procedure assumes the radar is operating on long pulse. If measurements are made using the short pulse mode, add 9 dB to the value obtained in step 5 above.

Figures 3 and 4 can be used in estimating echo intensity with WSR-1, 3, and 4 radars. When using this method two gain control settings must be calibrated. For this purpose the control settings will be determined by the procedure outlined below. The secondary gain setting should be redetermined occasionally to allow for changes in the radar components:

(1) Normal gain setting - A small amount of grass visible on the A-scope.

(2) Secondary gain setting - At normal gain setting locate an echo (at any range) that barely saturates the A-scope. Reduce the receiver gain to the threshold level of this echo and mark the control position as accurately as possible.

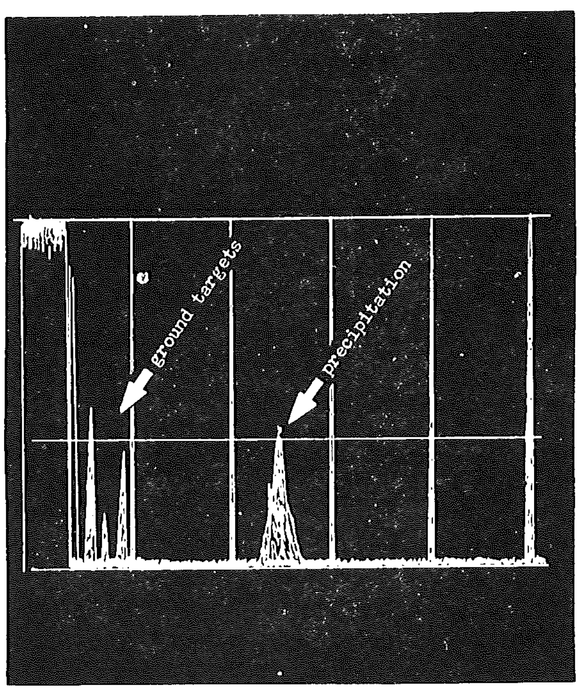

Figure 1. Precipitation Echo with Attenuation Introduced to Bring Signal Amplitude down to level of middle line.

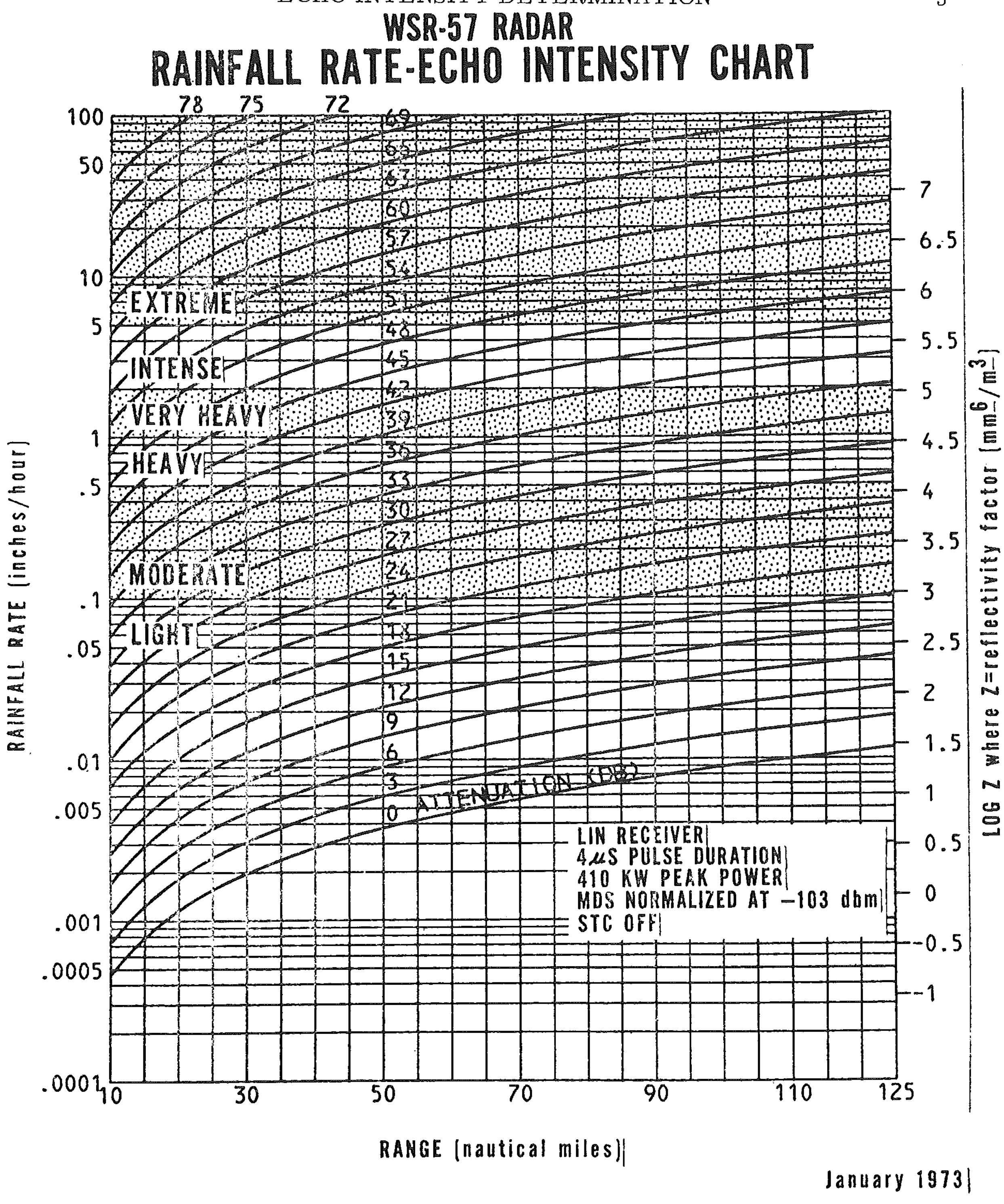

Figure 2. Rainfall Rate-Echo Intensity Chart

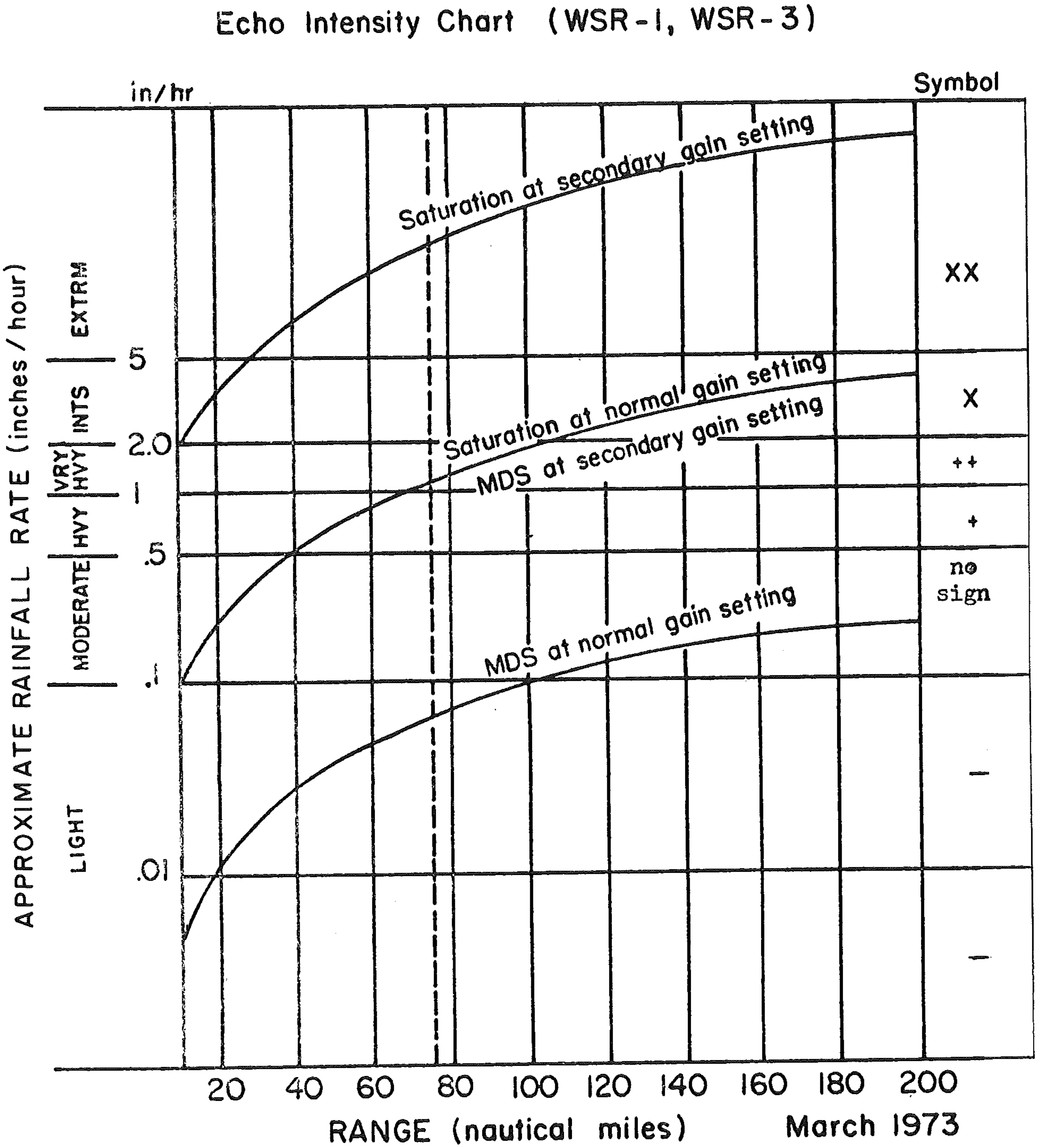

Figure 3. Echo Intensity Chart (WSR-1, WSR-3)

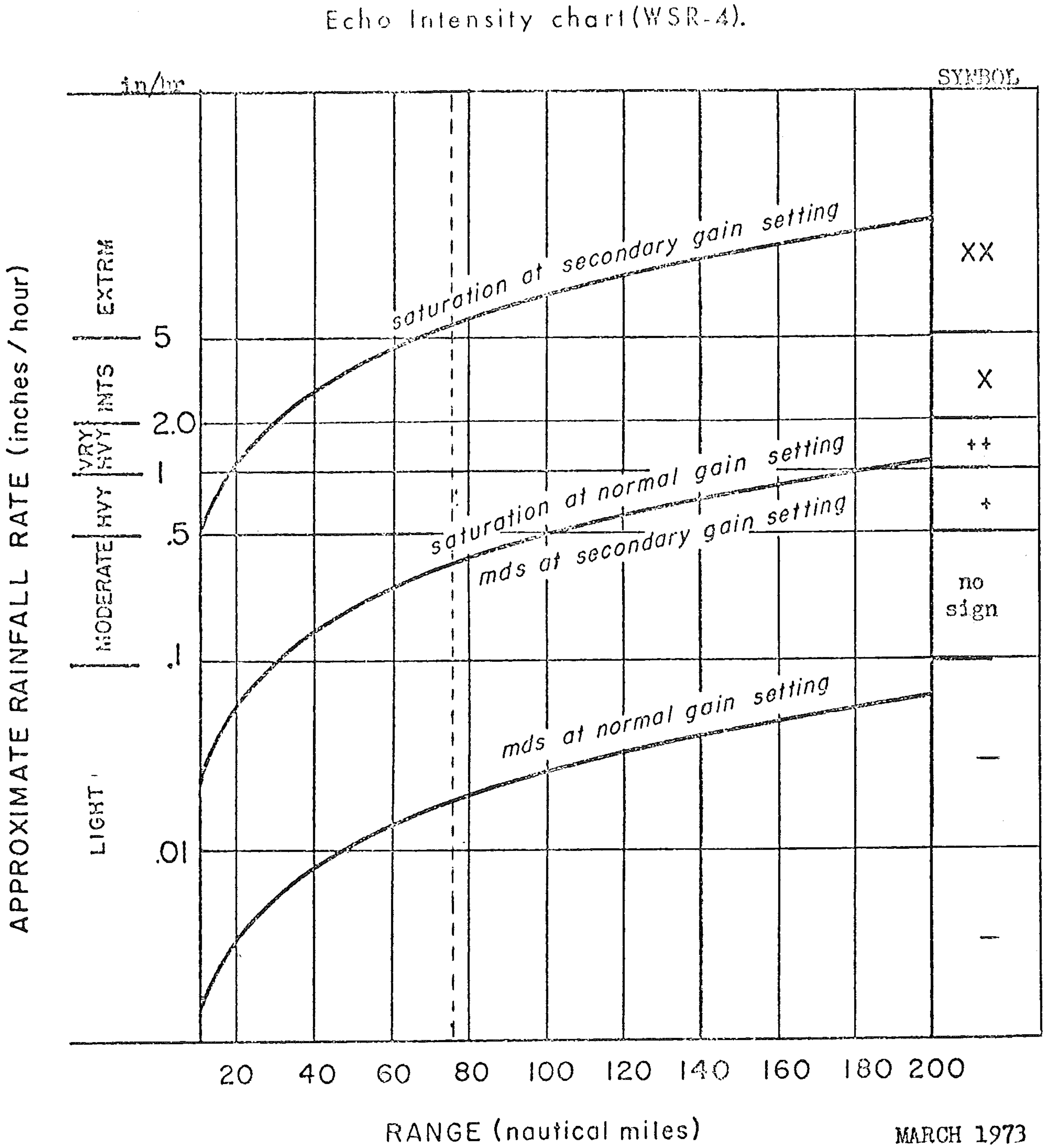

Figure 4. Echo Intensity Chart (WSR-4)

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

OPERATING INSTRUCTIONS FOR WBRR RADAR REMOTE DISPLAYS

With the increasing use of radar remote displays by government and nongovernment users, the need for standardized operational procedures and format has become more apparent. The following instructions supplement previous instructions on the subject.

I. TRANSMITTER SITES.

a. Transmitting stations should perform the daily checks on the WBRR transmitter as outlined in the "Engineering Handbook No. 6, Radar Systems, Section 4.4: Interim Maintenance Schedule for WBRR-68 System." It is especially important that these checks be performed during PPINE periods so the equipment can be repaired in advance of a period of precipitation in the event of a malfunction.

b. Make certain that the station call letters and range in use are written on the DID. These are normally part of the map overlay, but if the station call letters or range numerals are missing, they should be written in until the map overlay can be revised. This is particularly important at stations that can be dialed-up.

c. Range marks should always be transmitted over the WBRR. DID maps have an arc of 10° azimuth that coincides with the 100- and 200-mile range marks. Observers should check the on-line monitor to be sure the DID marks and range marks coincide; otherwise the echoes are erroneously related to the map.

d. The DID map overlay should be checked periodically to determine whether corrections and additions are necessary. Revised overlays may be procured by sending an updated sketch to Regional Headquarters along with a brief justification for the change. Upon approval the new DID will be requested from Headquarters, Attention: W143.

e. Echoes in the intense or extreme intensity category, or those associated with severe local storms, should be identified separately. The data must either be updated or removed, more often than once per hour.

f. Observers should check WBRR transmissions on the on-line monitor to ensure annotations are valid and not obscured by echoes which have moved over the handwriting. Normally, these checks can be at H + 15; however, they should be more often during rapidly changing situations. The validity of operational status annotations, i.e., PPIOM, PPINE, should also be checked periodically.

g. At stations that have a VIP, operation should be limited as much as practicable to C-log and 125-nmi range, even when some echoes are observed beyond that range. If there are particularly significant echoes beyond 125 nmi in addition to echoes within 125 nmi, the 250-nmi range should be used. Of course, if echoes are present only between 125 nmi and 250 nmi, the 250-nmi range should be used. Stations that do not have a VIP should continue operation on standardized linear receiver.

h. Stations with dial-in capability should be alert to keep the Data Set in data mode as much as possible. This should be checked after every maintenance shutdown.

II. <u>RECEIVING STATIONS.</u>

a. Receiving stations should perform the daily checks on the WBRR recorder as outlined in the "Engineering Handbook No. 6, Radar Systems, Section 4.4: Interim Maintenance Schedule for WBRR-68 Systems." It is especially important that these checks be performed during PPINE periods so that equipment can be repaired in advance of a period of precipitation in the event of a malfunction.

b. The recorder may be turned to standby during extended PPINE situations. To switch the recorder to the standby mode, set the Delay Time Control on the infinite position. With the recorder in standby, pictures may be commanded manually. Personnel should be alert to the possibility of precipitation developing and should check the recorder periodically for new echoes, especially when conditions favor development.

c. Sample ground clutter displays should be posted near the WBRR display.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

WBRR PICTURE QUALITY CONTROL

Experience with the WBRR (Weather Bureau Radar Remote) equipment has indicated a need to establish guidelines for local control of equipment operation to ensure optimum picture presentation. At times, it is difficult to determine where the problem lies, but every effort must be made to ensure that the complete system is operating satisfactorily. The WBRR equipment is an adjunct, and should be considered an integral part, of the WSR-57 Radar system. The same high priority in keeping the WSR-57 Radar operational must be given to the WBRR system.

1. Required checks of the WBRR (65 and 68) transmitting and receiving equipment must be made in accordance with instructions outlined in Maintenance Schedules, Performed by Observer (green copy) of Engineering Handbook No. 6.

2. If the WBRR receiver is not operating satisfactorily, then a determination of where and what the trouble is must be made by the affected office. An entry should be made on WS Form H-10, and if the electronics technician is available the problem should be brought to his attention promptly.

3. When a good quality picture is not being received on the WBRR receiver equipment, and normal operator adjustment of the equipment cannot rectify the problem, a call should be made to the radar transmitting site to determine if the WBRR transmitter is at fault (by checking on-line monitor), or if the trouble lies in the telephone lines or the receiver.

4. If the trouble appears to be in the receiver or telephone lines, then the electronics technician at the receiving station should be notified, even during his normal off-duty hours, in accordance with instructions contained in the Weather Service Operations Manual, chapter H-50. An exception can be made to delay recalling the electronics technician until the next scheduled shift if echoes are not expected or the WBRR receiver office does not expect radar activity to affect its area of responsibility.

5. When electronics technician help is needed at the transmitting site, procedures similar to those stated in 4. should be followed.

6. The radar operator should daily check, by "hot line" telephone, the operational status and quality of the picture on Weather Service WBRR receivers which have direct telephone line connections to his transmitter. Any problems common to all receivers should be brought to the attention of the electronics technician at the transmitter site, and problems not common to all receivers should be directed to the electronics technician at the receiver station.

7. Personnel at the WBRR receiver sites, including offices with dial-in capability, have an obligation to monitor performance, carry out checks, and to note malfunctions of WBRR equipment on WS Form H-10. These personnel should not wait until echoes are observed to note any malfunctions or deterioration in the quality of the display; rather they should notify the electronics technician and enter the problem on the form during PPINE periods so that the equipment can be serviced in advance of a period of precipitation.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

BACKUP PROCEDURES FOR NWS RADARS AND RADAR REMOTES

Backup procedures for National Radar Network radars are contained in paragraph 12.4, "Transfer of Network Responsibilities," Part A, of the Weather Radar Manual. This instruction refers to the transmission of RAREPS by an alternate radar when the primary radar is out of service. Expansion of the radar network and the WBRR program have made it necessary to supplement these backup instructions as follows:

1. Radar stations should coordinate with the appropriate WSFO and adjacent NWS and/or primary military radar stations prior to shutting down the radar for routine maintenance. This is to avoid having adjacent radars simultaneously out of service for maintenance.

2. Radar stations with a WBRR radar remote transmitter that goes out of service when significant echoes are present will notify a user NWS office(s) that is on a dedicated line about the outage and its expected duration. During the outage the radar observer will be particularly alert to call the user office(s) and provide briefing concerning significant echoes affecting areas of mutual interest. At the same time the user office will be expected to utilize regular and special SDs and hourly radar statements received via NWWS, RAWARC, or any other available method. An NWS user office with dial-up capability should also obtain copy from another network radar with WBRR transmitter if the latter's radar coverage is significant to the user office.

3. NWS offices whose WBRR recorder on a dedicated line becomes inoperative will alert the transmitting office to the failure and the probable duration, requesting prompt notification by hot line or other method of significant echoes that are affecting or may affect the using office's area of interest. The user office will also take the steps described under 2. above to utilize the SDs and radar statement issued by the parent radar station or other appropriate radars.

4. Where an NWS office is being supplied radar data from an Air Force radar via a remote link, backup procedures should be established. Separate contingency plans should be developed for cases where (1) a radar breakdown occurs, and (2) the radar remote fails. When a radar breakdown occurs, nearby radar stations should be so notified and requested to supply radar data on significant precipitation echoes by the most expeditious means. If only the remote system fails, the radar data should be communicated promptly to the NWS office via an alternate route, such as teletypewriter and/or telephone.

All radar stations and offices with remote displays should review this instruction and take action as necessary to put into effect backup procedures.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

MULTIPLE-ACCESS DEVICES FOR DIALING INTO WBRR TRANSMITTERS

Each of our WBRR transmitters are equipped so that it is possible to dial to the transmitter from a regular telephone, then connect a WBRR receiver to the transmitter through the telephone. Thus, for the price of a direct-dialed call, a user can get a picture of the radarscope from any of our radars having WBRR transmitters. The user may connect his WBRR receiver to his telephone in one of three ways: by induction coupler, by a data access switch (DAA) in the telephone, or through a 602c modem supplied by the telephone company. The latter method is necessary if the particular WBRR receiver will receive only AM signals, because the 602c will accept the FM signal from the multiple-access dialing device and convert it for input to the AM receiver. If the receiver will accept FM signals, either of the first two methods may be used. The induction coupler may be owned by the user while the data access switch in the telephone is rented from the telephone company for about $4.00 per month.

The equipment now being purchased is called the NWS Multiple-Access Device (MAD). These MAD units are currently in operation at all WBRR transmitter locations. Each unit will initially have capability to accept up to six simultaneous calls, the actual number being limited by the number of telephone terminals assigned to each transmitter. Initially we will have only one or two private terminals, which will be used only by NWS, and one or two public terminals used by both NWS and others. In addition, at some locations there will be a terminal used exclusively by the FAA.

The MAD accepts a modulated AM signal from the WBRR transmitter, converts it to an FM signal and distributes it to calls on the various telephone terminals. It will not answer any calls when the WBRR transmitter is in store mode, and it provides an automatic cutoff for all callers, the length of each connection depending on the number of callers simultaneously connected. The greatest number of frames a caller can get is two complete plus a partial, and the least number is one complete plus a partial. Counters on the face of the MAD indicate the number of busy signals it has given, to help us determine the number of telephone terminals needed.

2 MULTIPLE-ACCESS DEVICES FOR DIALING INTO WBRR TRANSMITTERS

Most NWS forecast offices and Regional Weather Centers will have capability to dial to any WBRR transmitter. In addition, some Weather Service Offices will also be so equipped, as will the Emergency Warning Branch of Weather Service Headquarters and certain Regional Headquarters. The FAA is equipping a number of its facilities, including the Central Flow Control Facility at Washington, D.C. There will also be quite a number of nongovernment users. Interest in dialing radar pictures is high among airlines, television stations, and private meteorologists, and we can expect these and possibly others to make heavy use of the dialing possibilities during critical weather situations. It will be necessary, therefore, to have certain telephone terminals reserved for NWS use exclusively, and to guard these numbers with diligence. All nongovernment users will be required to sign an agreement concerning the use of dialed radar data and the limits of NWS responsibility, and will be provided with a list of telephone numbers they are eligible to use. This is the only authorized disclosure of any of the telephone numbers associated with the MADs. No one at any WSFO, WSO, or WSMO is authorized to disclose any of the numbers to anyone. Those numbers known to any of these offices will not be displayed such that a visitor might see them, and they will never be transmitted by telephone to anyone.

The addition of MADs to our WBRRs points up necessary limitations to flexibility in our use of the radars. During the time when the radar is not rotating normally the WBRR transmitter goes into store mode and the MAD will not accept calls. Further, there is an additional 90 seconds or so after normal rotation is resumed before the MAD will accept calls, because it takes about that long to build a picture in the WBRR transmitter. Obviously, then, we should keep both the number and duration of nonnormal rotation (off periods) to a minimum. When possible, off periods should be at regular intervals, and the DID updating should be done during the same off period in which the hourly observation is made. This obviates a separate off period for updating.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

WBRR-68 FACSIMILE RECORDER DIAL-IN INSTRUCTIONS

1. The telephone coupler should be located at least 3 feet from any magnetically radiating devices, such as power transformers, teletypewriters, etc. Once recording starts, care should be taken that the coupler is not disturbed, and that objects are not dropped on the surface on which the coupler is placed.

2. Pick up the telephone handset and dial the appropriate telephone number. These are guarded numbers. Only the RH and NWSH have authority to give these numbers to any person or agency.

3. Listen for the phone to answer. It will automatically answer on the first ring. After it has answered, you will hear a warbling sound. Insert the handset into the coupler. The handset ear piece should be inserted in the coupler cup marked EAR.

4. Printing will commence, and the WHITE LEVEL and CONTRAST controls should be adjusted immediately.

5. It is desirable to monitor the recorder operation throughout the dialed call. Calls will be automatically terminated when calling into the Multiple Access Dial-In System, but the recorder will continue to run and max printing will occur until the handset is removed from the coupler.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

AGREEMENT FOR REMOTING OF WEATHER RADAR DATA

It is our policy to encourage the dissemination and effective use of radar data through such channels as industrial meteorologists and TV stations. The attached sample agreement forms were designed to provide a basis for remoting radar data to nongovernment users by means of a transmitter provided by the National Weather Service.

Three types of sample agreement forms are attached. Each type is identified by a small number in the upper left corner of the first page. Type "a" is appropriate for dial-in service (when available), type "b" is to be used for a leased line connection, and type "c" is designed for the case where an intermediate distributor desires to make the radar available to a number of clients.

An appropriate agreement form for (a) dial-in, (b) leased line, or (c) intermediate distributor will be signed by the Regional Director on behalf of the Government. Forms (a) and (b) will be renewed annually and form (c) every 5 years on the initiative of the regional headquarters. Proposed agreements relating to dial-in service will be coordinated at the OMO level, and proposed agreements pertaining to interregional leased lines will be coordinated between the appropriate regional headquarters.

If significant changes in wording are necessary, or if unusual arrangements are contemplated, prior coordination will be carried out with the NWS headquarters in consultation with the NOAA General Counsel. Where office quarters are leased it should be ascertained whether the lease contains any provision prohibiting the contemplated installation of equipment or use of the premises.

The following pages contain a sample of the three agreement forms.

Form a

UNITED STATES DEPARTMENT OF COMMERCE

WASHINGTON

AGREEMENT FOR ACCESS TO NATIONAL WEATHER SERVICE RADAR DATA USING DIAL-IN TELEPHONE FACILITIES

THIS AGREEMENT is entered into on this __________ day of ____________, 19______, between the United States of America, Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, hereinafter referred to as the Government, and ________________ ____________________________________, hereinafter referred to as the User. In order to provide for the use of weather radar data the parties do hereby mutually agree:

RESPONSIBILITIES.

A. Government agrees —

(1) To authorize the User to dial in, using commercial telephone facilities, to any suitably equipped "Weather Bureau Radar Remote" (WBRR) system for the purpose of obtaining radar data.

(2) To furnish the User, upon request, the unlisted telephone numbers providing access to WBRR systems.

(3) To reserve the right to authorize remoting to others and not to vest any right to the User or to any particular Users.

B. User agrees —

(1) To protect from publication, or other dissemination, the unlisted telephone numbers providing access to WBRR systems.

(2) To give full credit and identification to any interpretations of the images on the radarscope that are furnished by Government personnel and to take due care to avoid the implication that interpretations by others are those of the Government.

(3) For telecasting or other release of radar-derived information to the general public:

a. No visual commercial message shall be superimposed on the picture of the Government radarscope at any time; there shall be nothing in the announcements associated with those telecasts to indicate or imply that the Government endorses any commercial product advertised.

b. All interpretations of images displayed on the radarscope display shall be made by a qualified employee of the Government, or by an individual who has demonstrated previous experience in weather radarscope interpretation, and is a Certified Consulting Meteorologist or has qualifications equivalent to those required for Professional Membership in the American Meteorological Society.

(4) To pay all costs and expenses resulting from this agreement.

(5) To assume full responsibility for the use made of any information telecast or otherwise disseminated, and to hold the Government and its employees harmless for any damage that may arise from this agreement.

(6) To obtain any necessary permits and to abide by all applicable rules, regulations or laws pertaining to agreements with the Government.

EFFECTIVE DATE. This agreement is effective as of __________________ and shall be renewed annually unless terminated at any time, with or without cause, by either party on written notice to the other. Such notice shall be effective on date of mailing. Request for renewal should be forwarded to ____, 30 days prior to expiration date.

LIMITATION. The Government cannot guarantee that the radar or remoting system will operate continuously.

COMPENSATION. The benefits accruing to each party shall be full compensation without further liability of either party to the other.

IN WITNESS WHEREOF, the parties hereto have executed this agreement as of the date first written above.

USER (Insert Name of Company)	UNITED STATES OF AMERICA Department of Commerce National Oceanic and Atmospheric Administration National Weather Service
BY:______________________	BY:______________________
Title:______________________	Title:______________________

Form b

UNITED STATES DEPARTMENT OF COMMERCE

WASHINGTON

AGREEMENT FOR ACCESS TO NATIONAL WEATHER SERVICE RADAR DATA

THIS AGREEMENT is entered into on this __________ day of ____________, 19______, between the United States of America, Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, hereinafter referred to as the Government, and ________________ ____________________________________, hereinafter referred to as the User. In order to provide for the use of weather radar data the parties do hereby mutually agree:

RESPONSIBILITIES.

A. Government agrees —

(1) To authorize the User, at no cost to the Government, to obtain from the ____, radar telephone transmission signals of the Government radar located at ____.

(2) To reserve the right to authorize remoting to others and not to vest any right to the User or to any particular Users.

B. User agrees —

(1) To give full credit and identification to any interpretations of the images on the radarscope that are furnished by Government personnel and to take due care to avoid the implication that interpretations by others are those of the Government.

(2) For telecasting or other release of radar-derived information to the general public:

a. No visual commercial message shall be superimposed on the picture of the Government radarscope at any time; there shall be nothing in the announcements associated with these telecasts to indicate or imply that the Government endorses any commercial product advertised.

b. All interpretations of images displayed on the radarscope display shall be made by a qualified employee of the Government, or by an individual who has demonstrated previous experience in weather radarscope interpretation, and is a Certified Consulting Meteorologist or has qualifications equivalent to those required for Professional Membership in the American Meteorological Society.

(3) To pay all costs and expenses resulting from this agreement.

(4) To assume full responsibility for the use made of any information telecast or otherwise disseminated, and to hold the Government and its employees harmless for any damage that may arise from this arrangement.

(5) To obtain any necessary permits and to abide by all applicable rules, regulations or laws pertaining to agreements with the Government.

EFFECTIVE DATE. This agreement is effective as of ________________, and shall be renewed annually unless terminated at any time, with or without cause, by either party on written notice to the other. Such notice shall be effective on date of mailing. Request for renewal should be forwarded to ____, 30 days prior to expiration date.

LIMITATIONS. The Government cannot guarantee that the radar will operate continuously.

COMPENSATION. The benefits accruing to each party shall be full compensation without further liability of either party to the other.

IN WITNESS WHEREOF, the parties hereto have executed this agreement as of the date first written above.

USER (Insert Name of Company)	UNITED STATES OF AMERICA Department of Commerce National Oceanic and Atmospheric Administration National Weather Service
BY:______________________	BY:______________________
Title:____________________	Title:____________________

Form c

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL WEATHER SERVICE

AGREEMENT FOR THE DISTRIBUTION OF RADAR DATA

WHEREAS the National Weather Service of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, hereinafter referred to as the Government, operates a network of weather surveillance radars, many of which will be equipped with data remoting equipment, for the purpose of providing weather information to other offices, and to the public, and

WHEREAS the dissemination of such information is in the public interest as a matter of convenience and necessity, and

WHEREAS ____, hereinafter referred to as ________________________________, desires to provide and operate a system to disseminate the radar data and related weather information to users,

NOW, THEREFORE, in consideration of the premises, ________________ is hereby authorized to connect to the C2 conditioned leased lines in telephone company facilities wherever such lines are available subject to the following terms and conditions:

A. No equipment will be installed in Government quarters.

B. Connections and dissemination of data under this agreement will not incur any expense on the part of the Government.

C. Users of data disseminated under this agreement are not authorized to use such data for public distribution by means of commercial television unless permitted by specific agreement.

D. The Government cannot guarantee that the radar and remoting equipment will function at all times.

E. ____________________ will keep the Government advised of the locations of all receiving terminals.

F. The Government will furnish ____________________ a proposed installation schedule for planned radar data transmitters upon request.

G. ____________________ will submit a notice of intent to attach to a remoting transmitter at least 30 days in advance to the appropriate National Weather Service Regional Headquarters.

H. ____________________ agrees that the granting of this authorization by the Government does not vest in him any exclusive or permanent right to receive this service, and that the service may be modified or suspended at any time at the discretion of the Secretary of Commerce, without recourse.

I. This authorization is for a term of five (5) years from ______________________________, and expires ______________.

IN WITNESS WHEREOF the parties have hereunder set their hands and seals this ______________________ day of ______________.

UNITED STATES OF AMERICA
Department of Commerce

______________________________ for Secretary of Commerce

____

____

____

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

GUIDELINES FOR THE USE OF THE RADAR REMOTE (WBRR) AND THE VIDEO INTEGRATOR AND PROCESSOR (VIP) AT FIELD OFFICES

BRIEF DESCRIPTION OF SYSTEM COMPONENTS

The WBRR-68 provides PPI displays to NWS stations and other users that are remote from a WSR-57 radar site. The WBRR site may have a "dedicated" line to a particular radar position and/or a "dial-in" line to various WSR-57 radar positions. Additional information is provided to the users by the radar operator through the Data Insertion Device (DID).

The WBRR is capable of providing the user with a current PPI display out to a range of 250 nmi. In addition, normally at hourly intervals, the radar operator provides annotation, i.e., speed and direction, tops, type and intensity of the echo, through the use of the DID. The result is that the WBRR user has a nearly continuous and current PPI display that greatly enhances other forecasting tools for use in preparing Metro-weather Summaries (Nowcasting), aviation forecasting, and issuing weather warnings.

Since the WBRR, an adjunct to our radar systems, is relatively new and is such an important source of information, each WSFO with a WBRR should assign a meteorologist as the station project leader for implementing a meaningful program to fully utilize this new information in the office's forecast and warning services.

The VIP is operational at some WSR-57 sites and is programmed for the near future at others. The VIP processes the radar's logarithmic receiver output to show up to six levels of intensity to a range of 125 nmi. The intensity levels correspond to preselected categories of estimated rainfall rates. The VIP constantly provides a display of echo intensity levels from which the operator can determine echo intensity change and movement.

The six intensity levels are contoured on the radar PPI for all echoes by using gray, white, and black for levels 1, 2, and 3, respectively, and the shading is repeated for levels 4, 5, and 6. This contoured display is also transmitted to the WBRR; however, the intensity level display (on facsimile) is different than on the radar PPI due to a color reversal similar to a negative in black and white photography. On the WBRR, the levels will be light shading, black, and white for levels 1, 2, and 3, respectively, and repeated for levels 4, 5, and 6. The operator at the radar site can select any one or more levels for display on the radar PPI to further isolate intense echoes. For example, the operator may select levels 4 and 5 for display to easily isolate the stronger echoes. It should be noted that this has no effect on the display seen at the WBRR site as all levels that exist are always transmitted. The VIP will insert a special range marker at 10 and 125 miles which indicates the limits of integration on the WSR-57 display.

A VIP display can be a great advantage to the radar operator, forecaster and weather service specialist (WSS) at the WBRR site. It cuts down on the time necessary to report, it constantly monitors echo intensities, and gives the operator, forecaster and WSS a quick idea of echo intensity and an idea of the associated rainfall rate and intensity of weather.

It is necessary that the VIP be routinely calibrated at the radar site to present the proper display. The calibration will be done weekly by the electronics technician. The WBRR also requires routine calibration and constant picture quality control at the remote office to insure that optimum display is obtained at all times. The picture quality control of the WBRR is especially critical when receiving a VIP contoured display and should be monitored by assigned personnel, viz., forecaster or WSS, at the station.

When a good quality picture is not being obtained, it may be possible to improve the quality with normal operator adjustments as follows:

A. Adjust the contrast control to get the best black-to-white ratio. The contrast control is used to compensate for varying contrasts which are transmitted by the slo-scan transmitters. With proper adjustment, proportional signals from the weakest to saturation will be proportionally recorded. If the contrast is set too high, the proportional response will be lost, and the recording will tend to contain only black and white areas. Clockwise settings increase contrast.

B. Adjust the white level control to remove stray shading in the white area. The white level control is used to compensate for the varying minimum video signal levels which are transmitted by the slo-scan transmitter. Careful setting of the control is required to print the weakest data without printing a noise background throughout. Clockwise settings increase the white content, reducing the printing of weak signals.

C. Repeat steps A and B, if necessary, until the desired three levels of shading are acquired.

If the picture quality is not improved by these adjustments, check to see if there is transmitter or line trouble. If, after following this procedure, it is determined that the problem is at the receiver site, the electronics technician should be notified.

OPERATING INSTRUCTIONS.

The purpose of this section is not to provide complete and explicit operating instructions, but rather to provide a guide to where some of the important ones are located and to supplement existing instructions.

A. WBRR (and DID).

1. DID Updating.

The DID should be updated at the hourly observation times or as often as required to describe changes in the mode of operations and in echo parameters if the changes are not readily observable on the remoted display. Even if the radar operator is making every effort to keep the DID updated as required, the WBRR receiver sites should be aware that there may be periods when other priorities do not permit the radar operator to keep the DID current. While this situation is not desirable, it may arise, and DID information such as tops, direction, and speed may no longer be representative of the existing echoes. This is an especially serious problem during rapidly changing weather situations and should be fully recognized by the users of WBRR information.

There will be times when the radar operator, because of a request from one of his WBRR users, may change the mode of operation, such as from contoured-log to log presentation, or from STC ON to OFF, for a brief time. Every effort should be made to note this change by using the DID. This may not always be possible, and the user should be wary of unheralded changes of this nature.

2. DID Care and Handling.

Special care and handling should be taken at all times in order not to scratch or chip the paint from the DIDs. These homolite discs are easily scratched. A soft cloth or tissue should be used to erase the annotations. The two knobs on the disc should be used when it is necessary to handle them. Be very selective as to the type of pencil that is used to make the annotations. Tests have shown that the best pencil to use on the DID is the J.S. Staedtler "Mars-Omichron" marking pencil. These pencils can be ordered from the Central Logistics Supply Center at Kansas City, Mo. in the following colors: yellow, red, green, blue, and white. The blue pencil should be used for making the annotations on the DID because it has been found that this color produces a more vivid picture when transmitted to the receiver sites. These "Mars-Omichron" pencils can also be used on the reflection plotter of the WSR-57.

3. Other Sources of Instruction.

a. Weather Radar Manual (WBAN) part A, section 13.

b. Weather Radar Manual, part C, section III, Issue Nos. 3, 4 and 7.

B. VIP.

1. General Information.

The VIP provides intensity contours only out to 125 nmi even if the maximum range of the radar system is set for 250 nmi. That means that when the radar and the WBRR are set for 250 nmi range, the WBRR presentation will be contoured out to 125 nmi and no contouring will be indicated at the longer ranges, 125 to 250 nmi. (Intensities obtained beyond 125 nmi by any method are not considered to be accurate. Users should be acutely aware of the mixed presentation when the WBRR is set at 250 nmi and not draw false conclusions about changes in intensity when echoes move from one type area to another.

Because the mixed presentation has these drawbacks, and also to facilitate establishing continuity of echoes, it is recommended that for normal operation the WBRR be set at 125 nmi. However, because there are times when the radar operator or one of the users deems it important to remote information beyond 125 nmi, this may be done with discretion.

2. Other Sources of Instruction.

Weather Radar Manual, part C, section III, issue No. 1.

C. Antenna Elevation.

Any deviations from the normal setting of antenna elevation (one-half degree) should be noted on the DID to provide this information to the WBRR sites.

INTERPRETATION

Radar interpretation is not an easy task because it requires a basic understanding of the radar itself and its limitations. Factors such as beam width, beam height, pulse length, wavelength, and other radar parameters, all influence the radar display. A basic understanding of radar characteristics enables the user to better interpret what is displayed on the PPI. Phenomena such as anomalous propagation and "second trip" echoes, both of which can cause misleading interpretation of the PPI display, should be thoroughly understood by the user. A complete discussion of PPI interpretation is beyond the scope of these guidelines but is covered adequately in the Weather Radar Manual (WBAN) Part B.

The WBRR user should be aware that there are several things that he can do to produce a more complete picture of what is occurring. The forecaster, with pictures at a regular interval, can determine speed and direction for echoes that will affect his area. This can be helpful because sometimes the radar operator doesn't provide these for each cell.

The motion of a large echo area may be difficult to determine. This motion may be, but not necessarily, related to the movement of a synoptic scale system such as a Low or trough. For this reason it is important for the forecaster to determine the motion of the synoptic system because it usually determines the motion of the precipitation area. Within such an area there may be strong cells with a motion different from the area. These cells have been found to move with the upper-level wind which can be helpful in determining areas of heavier precipitation. Large convective echoes (15 nmi or greater in diameter) composed of many individual thunderstorms tend to move with a speed less than the 850 to 300 mb mean layer wind and to the right of the direction. This is a result of the formation of new cells predominately on the right flank. The thunderstorm complex tends to grow or propagate in that direction and its motion will approach a steady state. This can be useful in extrapolating future motion of the thunderstorm complex in the absence of sudden changes in the size of the complex.

6 GUIDELINES FOR THE USE OF THE WBRR AND VIP AT FIELD OFFICES

A VIP display will give the forecaster and Weather Service Specialist (WSS) a reasonable idea of the rainfall from a particular echo and by knowing speed and direction of its motion will provide a useful tool in flash flood forecasting. For example, if an echo with an intensity level of 4 or 5 is observed to be satisfactory or very slowly moving it will undoubtly produce a significant rainfall amount. When the radar rainfall estimate approaches the amount needed for flooding, the issuance of flash flood warning should be considered. The radar operator will keep the WBRR users informed of severe weather echoes first by telephone and then through the use of the DID. Some indicators of this type of echoes include: those of very strong intensity (level 4 or greater), tops within 5,000 ft of the tropopause or exceeding it, tops equal to or greater than 50,000 ft, hooks, intersecting intense echoes, and line echo wave pattern (LEWP). Any of these may indicate potentially severe weather and should be watched closely.

The WBRR user is able to continuously monitor potentially severe echoes for aid in issuing timely severe weather warnings. The forecaster and WSS should become familiar with all the annotations used by the radar operator and their interpretation. One important part of the observation that can only be furnished by the radar operator is the measurement of echo tops. The WBRR user is completely dependent on the radar operator to indicate echo tops on the DID. As pointed out earlier, their information can become incorrect very quickly in a rapidly growing convective storm.

Interpretation of the VIP contoured display should also be done carefully. Of prime importance to the WBRR user is picture quality control because if the WBRR is not properly calibrated it may not show all the levels that are displayed on the radar PPI scope. Intensity levels 5 and 6 indicate high rainfall rates but may also indicate hail and strong winds in addition to heavy rain. Certain sizes of hail when water-coated have a high reflectivity producing high intensity levels. Interpretation must be done with this effect in mind.

A confusing event that occurs quite often on a PPI display is that an echo will seem to separate as it moves closer to the radar site. This happens when two echoes at the same range are separated by less than one beam width. This causes the two echoes to be displayed as one larger echo on the PPI. If the two echoes move towards the radar, maintaining the same separation, the echo on the PPI will appear to separate. This happens because the beam width is directly proportional to distance from the radar site and once the echoes are separated by more than one beam width they will be displayed as separate and distinct echoes.

Winter precipitation, such as snow and drizzle, is difficult to detect because of the low reflectivity of snow (except for large water coated snowflakes) and the small drop size of drizzle. Drizzle is usually associated with stratiform clouds having low tops. The combination of the low tops and the fact that beam height increases with range due to the curvature of the earth's surface causes the radar to overshoot this type of precipitation. This problem can be especially critical for stratiform-type precipitation at ranges of approximately 75 nmi and greater. The result is that the radar may not detect the echo, which may lead the forecaster to believe that there is little or no precipitation in the area, when it is actually widespread. The forecaster should be aware of this detection problem, especially when trying to forecast the beginning or ending time of precipitation because the boundary of the area may not be detected. This could lead to a considerable error in the forecast time of the beginning or ending of precipitation. Because this problem is particularly acute with snow, it may be necessary to operate with STC off for short intermittent periods in the winter. If so, it should be noted on the DID.

For emphasis we repeat that the discussion presented here is not intended to be complete. Any of the previously mentioned references will give a fuller understanding of scope interpretation; also scope interpretation should be considered with regard to the current synoptic situation and current observations.

ADDITIONAL SUGGESTIONS FOR PROCESSING WBRR INFORMATION

Because the interpretation of radar echoes is not always straightforward the radar information should be integrated with other data to assist in thoroughly and correctly analyzing the existing weather and its probable causes. The concept of analysis of meteorological events, where much information from various sources is combined to obtain the true picture, is not new to forecasters. This approach must also be practiced when using radar information. To be more specific, it is recommended that some color shading or selected echo intensity levels on the WBRR facsimile charts be made in a systematic way for identification and emphasis. When important weather activity is observed, a few surface reports can be plotted in color directly on the facsimile chart. Also, to get a more complete, integrated picture, some upper-air winds fronts, trof positions and/or areas of PVA should be superposed on the radar facsimile chart. With all this information on one chart, a quick, mesoscale analysis is possible, leading to a better understanding of the situation.

8 GUIDELINES FOR THE USE OF THE WBRR AND VIP AT FIELD OFFICES

The VIP contoured display provides a great deal of information useful to the forecaster and briefer in preparing Metro-weather Summaries (Nowcasting), flash flood forecasting, and watching strong echoes for warning purposes.

Another handy feature of the radar facsimile display is that the charts received at regular intervals (viz., hourly) may be superposed on a light table to readily reveal the continuity of features in the radar echoes. In the past, by plotting the SD's (RAREPS) the movement of radar features have been noted; now, with the WBRR facsimile charts, the continuity, motion, and changes in intensity can be more easily obtained and with much greater detail. However, this requires that the mode of operation of the WBRR not be varied indiscriminately, say from 125 nmi to 250 nmi range of from contoured-log to log presentation, etc. We do not believe the few changes needed for short periods of time will cause problems in establishing continuity of systems. If it should pose a problem further systematic procedures will have to be considered.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

SERVICE BY WBRR TRANSMITTERS

The following is a list of WBRR transmitter sites with the locations they serve directly by a dedicated line.

WBRR TRANSMITTERS	SERVING DIRECTLY
Apalachicola, Fla.	Tallahassee, Fla. (WSO)
Athens, Ga.	Atlanta, Ga. (WSFO) Atlanta, Ga. (NAS) Greenville-Spartanburg, S.C. (WSO)
Atlantic City, N.J.	Philadelphia, Pa. (WSFO) Willow Grove, Pa. (NAS) Islip, N.Y. (FAA ARTCC) Lakehurst, N.J. (NAS)
Bristol, Tenn.	None
Brownsville, Tex.	None
Brunswick, Maine	Portland, Maine (WSFO)
Buffalo, N.Y.	None
Centreville, Ala.	Birmingham, Ala. (WSFO) Montgomery, Ala. (WSO)
Charleston, S.C.	Columbia, S.C. (WSFO)
Chatham, Mass.	Boston, Mass. (WSFO) Boston, Mass. (FAA) Quonset Point, R.I. (NAS) South Weymouth, Mass. (NAS)
Cincinnati, Ohio	Lexington, Ky. (WSO) Dayton, Ohio (WSO)

WBRR TRANSMITTERS	SERVING DIRECTLY
Detroit, Mich.	Lansing, Mich. (WSO) Toledo, Ohio (WSO) Cleveland, Ohio (WSFO) Flint, Mich. (WSO)
Des Moines, Iowa	None
Galveston, Tex.	Port Arthur, Tex. (WSO) Houston, Tex. (WSO) Houston, Tex. (FSS)
Garden City, Kans.	Dodge City, Kans. (WSO)
Grand Forks AFB, N.D.	Fargo, N.D. (WSO)
Hondo, Tex.	San Antonio, Tex. (WSFO) San Antonio, Tex. (FSS)
Huron, S.D.	Sioux Falls, S.D. (WSFO) Aberdeen, S.D. (WSO)
Kansas City, Mo.	Topeka, Kans. (WSFO)
Limon, Colo.	Denver, Colo. (WSFO) Pueblo, Colo. (WSO)
Marseilles, Ill.	Chicago, Ill. (WSFO) Chicago, Ill. (WSO) Rockford, Ill. (WSO)
Memphis, Tenn.	Memphis, Tenn. (WSFO)
Miami, Fla.	West Palm Beach, Fla. (WSO)
Monett, Mo.	Springfield, Mo. (WSO)
Nashville, Tenn.	Nashville, Tenn. (WSO) Knoxville, Tenn. (WSO)
Neenah, Wis.	Green Bay, Wis. (WSO) Milwaukee, Wis. (WSO) Madison, Wis. (WSO)
New York City, N.Y.	None

WBRR TRANSMITTERS	SERVING DIRECTLY
Patuxent River, Md.	Suitland, Md. (WSFO) Suitland, Md. (NESS) Washington, D.C. (WSO) Silver Spring, Md. (NWSH) Baltimore, Md. (WSO) Richmond, Va. (WSO) Andrews NAF
Pensacola, Fla.	None
Pittsburgh, Pa.	Pittsburgh, Pa. (WSFO) Pittsburgh, Pa. (WSO) Canton-Akron, Ohio (WSO)
Ellsworth AFB, S.D.	Rapid City, S.D. (WSO)
St. Louis, Mo.	None
Slidell, La.	New Orleans, La. (WSFO) Mobile, Ala. (WSO)
Waycross, Ga.	Macon, Ga. (WSO) Savannah, Ga. (WSO) Jacksonville, Fla. (WSO)

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

RADAR STATIONS' RESPONSIBILITIES DURING PERIODS OF SEVERE LOCAL STORMS

Station Instructions. Each office will prepare local instructions that briefly summarize the steps to follow in distributing watches, warnings, and other types of severe weather information and keep them preferably in a separate manual in a convenient location known to all employees. These instructions should be arranged by priorities and kept up-to-date at all times. Telephone numbers, etc., should be verified in advance of the storm season each year. Contacts by telephone should be kept at a minimum.

Adequate Personnel Coverage. Arrangements for adequate 24-hour-a-day coverage should be made when severe weather conditions are expected or are occurring, including periods when public severe weather watch bulletins have been issued in or within about 100 miles of the area of county responsibility.

a. Overtime, paid or compensatory, in accordance with the provisions of NOAA Personnel Handbook and subsequent directives updating these provisions, is authorized when necessary to fulfill a station's warning responsibility.

b. If possible, when severe weather conditions are expected or occurring, there should always be one person scheduled whose paramount responsibility is keeping abreast of the latest weather developments and issuing warnings when appropriate.

c. While there is no general restriction, special care should be taken in approving annual leave during critical seasons when the services of all employees may be needed in emergencies. MICs, in particular, should arrange to take leave during the period when storm frequency is lowest.

d. Severe weather outlooks (narrative and graphic) should be taken into consideration for daily planning purposes, such as making tentative arrangements for emergency staffing.

Continuous Surveillance. A continuous watch of the radarscope will be maintained whenever there is a threat of severe local storms in any part of the radar surveillance area, especially when severe weather watches have been issued for any part of that area. Additional staffing will be provided to accomplish this function and at other times whenever required by regional instructions. Radar offices should be particularly attentive to watch areas and regions within 100 miles of watch areas. Continuous radar watch is essential for locating early storm development and detecting important changes in echo intensity or echo configuration which are indications of severe weather. Whenever the radar becomes inoperative or is temporarily out for maintenance, adjacent radar offices will be informed and requested to provide continuous weather surveillance in the area normally covered by the inoperative radar.

Radar stations should coordinate with their WSFOs and adjacent radar stations prior to shutting down their radars for routine maintenance. Otherwise, a number of adjacent radars may be shut down for maintenance simultaneously.

Notification of Other Offices. Under its radar umbrella, the radar office constitutes the "eyes" of nonradar offices who are greatly dependent on the radar observer for detailed radar information about severe or potentially severe storms. Although intensities are not given for echoes detected beyond 125 nmi, radar stations are required to notify adjacent offices when significant echoes are detected beyond this range. Such echoes should also be brought to the attention of the appropriate forecast office. Whenever the radar indicates that potential or existing severe weather echoes are in or approaching another office's area of responsibility, these offices will be notified by the most expeditious means--hot-line, NAWAS, other telephone or RAWARC. If RAWARC is used, acknowledgment will be requested. If acknowledgment is not received within a few minutes, another means of communication will be used. To avoid the possibility of public misunderstanding, NWWS will be used for this type of coordination only as a last resort. When such notification is made, every effort should be made to insure that recipients of these data understand their significance.

Special attention should be given to echoes within about 30 miles of another radar, since these echoes may be difficult for the radar operator to analyze due to the ground clutter. Radar offices equipped with radar remote systems will update the annotations on the receiver display frequently enough to keep the receiving office fully informed of any significant changes in intensities, tops, echo configurations and movements. Coordination between the radar office and remote receiver site should also be effected by the radar remote system's "hot-line." A special effort will be made to furnish radar data to a WSO whose radar remote is inoperative.

Warning Responsibilities. Radar indications of existing or potential severe weather should be immediately brought to the attention of the office having warning responsibility for the threatened area. The responsible office would then issue the warning. However, there may be times when the responsible office cannot be contacted and the radar indications are such that a warning is imperative. Under these conditions, a backup office will be notified or the radar office will issue the warning for the other office's area of responsibility according to plans developed by appropriate regional headquarters. Such plans will usually be more applicable to National Weather Service Meteorological Observatories equipped with WSR-57s, since these offices are the primary source of radar data for nearby WSOs.

REFERENCES

Pertinent instructions may also be found in the NWS Operations Manual, chapter C-40 and the Weather Radar Manual, part A, chapter 10.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

RADAR STATIONS' RESPONSIBILITIES DURING PERIODS OF HURRICANES

Radar Office Responsibility. A radar office should notify NHC and the responsible HWO via RAWARC or by phone whenever its radar observation indicates the development of a tropical cyclone.

Scheduling of Electronics Technician Staff.

(1) Electronics Technicians. At those WSR-57 radar installations providing hurricane warning coverage, continuous 24-hour coverage by certified electronics technicians will be maintained whenever a tropical cyclone (tropical depression or greater) is expected to affect the area of responsibility of the installation within the next 36 hours. As other instrumental equipment may require attention that may be of importance to the overall coverage being provided, the technician must keep his office informed as to his location whenever a tropical cyclone is suspected or in progress in the area of responsibility of his station. The MICs at affected offices are responsible for keeping electronics technicians advised of conditions which require 24-hour coverage.

(2) Area Electronics Supervisor. During the season in which tropical cyclones are anticipated, it is the Area Electronics Supervisor's responsibility to maintain a continuous appraisal of the operational readiness of all systems in his assigned area of responsibility and see that all necessary maintenance and corrective procedures are vigorously followed. When it has been determined that a tropical cyclone is expected within the area, the Area Electronics Supervisor, through liaison with the MIC at the stations concerned, will ascertain that the radar, emergency power, and other station equipment is in good operating condition and that an adequate stock of spare parts and supplies is available.

(3) Emergency Electronics Assistance. When a station's technician complement is not sufficient to provide the required 24-hour coverage during the hurricane emergency, it will be the responsibility of the MIC to advise the Area Electronics Supervisor (AES) of this fact as soon as possible. It will be the responsibility of the AES to provide the backup staff necessary. He will consider first the technicians within his area of responsibility that may be spared without jeopardizing the station's equipment. If he is not able to supply the staff necessary, he should call on regional headquarters to detail technicians from another area. The AES should constantly be alert as to the best procedure to provide the required backup and always have a plan ready to staff the stations requiring assistance. When there is a hurricane emergency, the AES should locate his headquarters where his experience may prove to be most advantageous in keeping the equipment operating.

Recall of Staff on Leave. All employees of those offices that have hurricane warning service responsibilities, when absent on leave during the hurricane season, should keep their respective offices advised as to how they may be reached by telephone or other equally expeditious means should it become necessary to recall personnel from leave during emergencies. MICs or OICs will use discretion in recalling employees from leave. It should be noted that an employee may be reimbursed for travel expenses incurred when recalled from leave provided the employee returns to the place where he was on leave to resume his leave (see NOAA Travel Handbook).

Emergency Assistance and Overtime.

a. Advance Planning. Regional headquarters will insure that all offices have worked out plans, prior to the hurricane season, that will enable the offices to discharge their hurricane warning service responsibilities. Such plans may include overtime for the permanent staff, emergency detailed staff, emergency assistants, FAA personnel, and cooperators. Dispatch of additional personnel from interior stations to offices requiring assistance because of hurricane conditions is a responsibility of the appropriate regional headquarters. The Weather Service Headquarters (WXAP Division) will be prepared to detail Weather Service Headquarters personnel when requested by the regional headquarters. The Emergency Warnings Branch of WXAP will serve as the focal point for Weather Service Headquarters details and will be advised of intraregional details.

b. Overtime. To meet and discharge the Weather Service's warning responsibilities, required overtime should be authorized. Procedures for authorizing overtime are in the NOAA Personnel Handbook. It is expected that under most circumstances officials will find the use of emergency overtime to be the most satisfactory solution to their requirements for extra help during emergency periods.

c. Emergency Assistants. Emergency assistants may be hired locally to assist in carrying on station duties during hurricane emergencies. MICs or OICs of field stations have the authority to hire emergency assistants without prior approval from the regional headquarters and Weather Service Headquarters. See NOAA Personnel Handbook.

REFERENCES

Pertinent instructions may also be found in the NWS Operations Manual, chapter C-41 and the Weather Radar Manual, part A, chapter 11.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

OPERATION OF LOCAL WARNING RADARS

All National Weather Service radars which are not in the Synoptic Weather Radar Network shall be regarded as local warning radars. Under the conditions listed below, these radars should carry out a complete observing and reporting program in accordance with the basic instructions in the Weather Radar Manual.

(1) Severe local storms or thunderstorms of heavy or greater intensity are forecast or are observed within radar range.

(2) Upon request of another National Weather Service activity, such as SELS, RADU, or a nearby forecast office.

(3) When radar observations are required because of special circumstances, such as an aircraft emergency or accident.

If none of these conditions is in effect, it will not be necessary to enter routine data on Form MF7-60.

Cold season operation should be limited for radars of the WSR-1, WSR-3, and WSR-4 types north of 31° latitude. Operation must be limited because of sluggish rotation of the antenna in very cold conditions and a need to conserve spare parts which are in short supply. Also, the poor detection capability of these radars during light rain and snow conditions limits the usefulness of this equipment during the cold season.

The following guidelines should be observed under limited cold season operation:

(1) Stations north of 40° latitude should severely limit operation of the radar during the period November 1 to April 1.

(2) Stations between 31° and 40° latitude should severely limit operation of the radar during the period November 15 to March 1.

(3) Stations south of 31° have no period of limited operations.

(4) New local warning radar equipment have no period of limited operations.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

LOCAL WARNING RADARS

RADAR LOCATIONS	TYPE RADAR
Abilene, Tex.	WSR-3
Akron, Ohio	DECCA 41
Albany, N.Y.	WSR-3
Atlanta, Ga.	WSR-3
Austin, Tex.	WSR-3
Baton Rouge, La.	EEC-WR100-5
Binghamton, N.Y.	WSR-3
Bismarck, N.D.	VITRO MR782
Boston, Mass.	WSR-4
Cleveland, Ohio	WSR-3
Columbia, Mo.	WSR-3
Columbia, S.C.	WSR-3
Columbus, Ohio	WSR-3
Concordia, Kans.	WSR-4
Corpus Christi, Tex.	WSR-3
Flint, Mich.	WSR-3
Fort Smith, Ark.	WSR-3

RADAR LOCATIONS	TYPE RADAR
Fort Wayne, Ind.	WSR-3
Goodland, Kans.	WSR-3
Hartford, Conn.	WSR-3
Huntsville, Ala.	WSR-3
Indianapolis, Ind.	WSR-3
Louisville, Ky.	WSR-3
Lubbock, Tex.	EEC-WR100-5
Madison, Wis.	WSR-3
Meridian, Miss.	WSR-3
Mobile, Ala.	WSR-3
Muskegon, Mich.	WSR-3
Norfolk, Nebr.	WSR-1
North Platte, Nebr.	WSR-3
Omaha, Nebr.	WSR-1
Raleigh, N.C.	WSR-3
Rochester, Minn.	WSR-3
San Angelo, Tex.	WSR-1
Scottsbluff, Nebr.	WSR-3
Shreveport, La.	WSR-1
Sioux Falls, S.D.	WSR-1
Topeka, Kans.	WSR-3
Tulsa, Okla.	WSR-3

RADAR LOCATIONS	TYPE RADAR
Victoria, Tex.	EEC-WR100-5 (10cm)
Waco, Tex.	WSR-3
Wichita Falls, Tex.	WSR-1
Worcester, Mass.	WSR-1

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

PILOT REPORTS AT ARTC CENTERS

Introduction. Being located at the ARTCC provides the unique opportunity to collect and disseminate PIREPS, especially those from high altitude jet aircraft and low flying aircraft on an instrument flight plan. These two categories will supply many meaningful PIREPS, especially those with reference to layers, tops, turbulence, and icing. The majority of these reports come from regularly scheduled airline traffic and from pilots who are most experienced and familiar with adverse weather conditions.

Many of these reports can go no further than the controller, since in extremely busy periods he cannot take the time to initiate a call to the WSFC. Since you are looking at the same radar systems that the controllers are, you can recognize when an aircraft is in a position to give a needed report and can request one through the controller if the pilot has not already given one. The controllers are prone to call, since they need only dial on the "300" phone system, which requires dialing three digits. You have the option of going to the control room and consulting directly with the controllers when time permits.

If the task is performed diligently, you are in a position to feed large amounts of desirable data to the forecasters and briefers at a time when they are most needed.

Data Collection.

1. By far the largest number of PIREPS will be a result of the controller's initiating calls to you on the FAA "300" system phone. Upon receiving a call from one of the controllers, make notes on a sheet of scratch paper, being certain to obtain all the information required to fill in WBAN 12.

2. Fill in WBAN 12 using a new line for each separate report. It will not be necessary to fill in the time of entry, but be certain to obtain the time of the report and also to record the tail number of the aircraft if it is supplied by the controller.

3. If you are not receiving any PIREPS, but you note an aircraft near an area of echo coverage or near an area where you expect echoes to develop, call the controller in whose area the aircraft is flying and request him to contact the pilot and obtain a report.

4. When two men are on duty and time is available, have one of the men go to the control room and obtain PIREPS while the other is extracting the echoes from the scopes.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

INSTRUCTIONS FOR ENTERING FRAME COUNT NUMBER ON FORM MF7-60

Enter the frame count number when a new magazine is installed and also with the beginning of each new Form MF7-60 in the data block titled "Counter." WSR-57 radar stations equipped with the 16mm camera system should reset their counters to zero at the beginning of each new film roll. These instructions are to be carried out by all WSR-57 radar stations.

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

PROCUREMENT OF RADAR MAPS AND SCOPE OVERLAYS

The following arrangements have been made for preparation, initial distribution and annual resupply of radar maps and scope overlays. The Radar Section of DATAC, WSH, will arrange for the initial standard package of maps and overlays for each new radar station. This standard package includes the original and negative retained by the printer, plus supplies sent directly to the station. These supplies are:

300 copies, 250 nmi range, 28 x 28 (paper)
1000 copies, 250 nmi range, 10 3/4 (paper)
1000 copies, 125 nmi range, 10 3/4 (paper)
10 copies, 250 nmi range, 10 3/4 (acetate)
10 copies, 125 nmi range, 10 3/4 (acetate)

It will be the station's responsibility to maintain an adequate supply of these items. Annual supply requirements for maps and acetate overlays should be made by memo to WXAP, Regional Headquarters, by indicating the number of maps required and the month needed. The Regional Headquarters will arrange for this annual resupply with the Property and Supply Branch, (AD15), by informal letter.

To acquire nonstandard maps or acetate overlays, such as scope overlays of different ranges, the order should be placed by memo through Regional Headquarters, to Chief, Program Requirements and Coordinating Staff (W1x2).

FILE WITH SECTION III, OPERATIONS PROCEDURES FOR RADAR AND RADAR REMOTING

SELF-STUDY RADAR COURSE

Operations Manual Letter 72-6, Subject: Meteorological Technician Grades, states the special qualifications requirements for promotion in the integrated technician position. One requirement listed is the self-study radar course and the purpose of this issue is to describe this course.

The course is somewhat different than other self-study courses such as the Pilot Weather Briefer Course in that no specific lesson plan is provided. The technician or meteorologist intern studies from several sources and then takes an examination. After achieving a passing grade on the examination, the technician or meteorologist intern must demonstrate his ability to operate the radar and his familiarity with local procedures. A certificate to take radar observations will be issued when these two requirements have been met.

Sources of material for study include the booklet, "Introduction to Weather Radar," the Weather Radar Manual (WRM), and other text books on radar such as those by Hiser and Battan.

The examination is in three parts. Part 1, questions 1-50, is on radar theory. Study for this part of the examination should include the first three chapters of Part B, WRM. The next part, questions 51-80, covers radarscope interpretation. Most of the material in this section of the test is covered in chapters 4, 5, and 11 of Part B, WRM. The last part of the examination, questions 81-100, deals with observing and reporting procedures. All this material is covered in Part A, WRM.

A set of sample questions that will help define the nature and scope of the certification examination follows. The examination is open to all meteorological technicians and meteorologist interns, regardless of whether their present position is at a radar location or not. A record of those who pass will be maintained in the regional headquarters. Certification will not be accomplished for an employee, however, until his position requires he demonstrate an ability to operate the radar and a familiarity with local procedures.

Policy governing certification is covered in chapter B-61 of the Operations Manual.

Any office that does not have a copy of the Weather Radar Manual or the booklet, "Introduction to Weather Radar," can obtain these from the regional headquarters. Studying from other sources, while desirable, is not essential for satisfactory completion of the self-study course.

RADAR OBSERVER QUALIFICATION EXAMINATION

SAMPLE QUESTIONS

1. Radar is of great value because it

   (a) can replace all other observations within 100 miles of the radar.

   (b) can replace visual observations within the radar coverage area.

   (c) observes all clouds within 100 miles of the radar.

   (d) supplements conventional observations.

2. Weather radar is so constructed that it detects only hydrometeors.

   (a) true

   (b) false

3. A microwave transmitter has a frequency of 7500 mc/sec. What is the length of the wave emitted by the transmitter?

   (a) 40 cm

   (b) 4 cm

   (c) 3/4 cm

   (d) .075 cm

4. A radar is to be designed with a maximum range of 250 nmi. If we disregard circuitry delays, what is the least time interval allowable between pulses? (c = .162 nmi/microsecond).

(a) 5 microseconds

(b) 1550 microseconds

(c) 3100 microseconds

(d) 4050 microseconds

5. Other things being equal, a steep increase in temperature with height will

(a) cause super-refraction.

(b) not affect refraction.

(c) cause sub-refraction.

(d) immobilize the radar beam.

6. The power returned by a thunderstorm echo is half as great as noted 1 hour ago. This decrease in power would be expressed in decibels as

(a) $dB = 10 \log \frac{Po}{2}$

(b) $10\ dB = \log \frac{1}{2}$

(c) $dB = 10 \log \frac{2}{1}$

(d) $dB = 10 \log \frac{1}{2} \frac{Po}{p}$

7. In the radar equation, doubling the range will

(a) decrease the power returned.

(b) increase the power returned.

(c) eliminate the power returned.

(d) not affect the power returned.

8. Sensitivity Time Control (STC) is designed to

(a) change the sensitivity of the radar on successive sweeps.

(b) change the sensitivity of the radar on successive pulses.

(c) change the sensitivity of the radar at different ranges.

(d) none of the above.

9. Attenuation due to clouds is

(a) about the same for all weather radars.

(b) greater at a 3 cm than at 10 cm.

(c) greater at 10 cm than at 3 cm.

(d) insignificant for all radars.

10. A few large raindrops can return a stronger signal (have higher reflectivity) than many small drops.

(a) true

(b) false

11. Two radars, observing the same thunderstorm, may report a different MAX TOP because

(a) their sensitivities are possibly different.

(b) their antenna height and beam width may be different.

(c) of beam width effects, small errors in measuring elevation angles, and non-standard propagation.

(d) this could only happen if one radar is not calibrated properly, or is not operated properly.

12. The PPI shows only a band of echoes some 20 to 50 miles wide extending southward from near a low pressure center. The latest surface map analysis places a cold front extending from the low, but at a considerable distance west of the band of echoes. The most reasonable conclusion is that

(a) the front should be moved to coincide with the echoes.

(b) the orientation of the antenna should be checked if the map analysis is confirmed by surface pressure reports.

(c) the map analysis should be examined to make sure it is correct, but it is not necessary that the front position coincide with the echoes.

(d) the echoes are probably spurious, and should not be reported as weather.

13. Converging echoes, especially when there are unusually high echo speeds

(a) generally dissipate soon after the merger.

(b) will form a large amorphous mass of rainfall echo, with a resultant movement very near the wind in the 700-mb-to-500-mb layer.

(c) generally produce more severe weather, ranging from heavy rainfall to tornadoes.

(d) nearly always produce tornadoes in the area of convergence, denoted by a "V" notch along the edge of the resultant echo.

14. If an echo top is reported to be higher than the tropopause, we should

(a) assume an error was made in echo height measurement or in the transmission.

(b) assume an error was made in computing the tropopause height.

(c) assume a tornado exists with the echo.

(d) none of the above.

15. Assuming equal rainfall rates and storm size and speed, the most critical flash flood situation would result from

(a) a storm moving up basin (toward higher ground).

(b) a storm moving down basin.

(c) a storm moving across the basin.

(d) a stationary storm.

16. There are no echoes on the scope, although fog has recently formed in a wide area around the airport where the radar is located and the airport is closed to traffic. The radar operator learns that a light plane near the closed airport does not have enough fuel to reach an open alternate. The correct radar procedure is:

(a) Encode and transmit a special observation, even though it consists only of PPINE. Change camera frequency to one frame per two antenna revolutions, and continue until aircraft is out of the maximum range of the radar, or for 30 minutes after distress is relieved.

(b) Encode but do not transmit a special observation. Change camera frequency to one frame per two antenna revolutions, and continue until aircraft is out of the maximum range of the radar, or for 30 minutes after distress is relieved.

(c) Verify with FAA that there is an aircraft in distress, then encode but do not transmit a special, but do not change camera frequency unless echoes appear on scope.

(d) No action is necessary if there are no echoes on the scope.

17. The characteristic type of precipitation is defined, for convective systems, as

(a) the type that is predominant in horizontal extent through the system.

(b) the type that is associated with the maximum observed intensity in the system.

(c) the type reported from the station nearest the maximum observed intensity.

(d) the type most consistent with climatology and the area forecast.

18. The intensity of a thunderstorm decreased only slightly between observations, but dropped from the lower portion of the strong category (0.6 in/hr) to the upper extreme of the moderate category (0.4 in/hr). The correct encoding of intensity trend is

(a) --

(b) -

(c) NC

(d) +

19. The following echoes should generally be reported separately as especially significant echoes; those echoes with tops within 5,000 ft of a known tropopause height, those echoes with tops exceeding the height of the tropopause, and those echoes that equal or exceed 50,000 ft.

(a) true

(b) false

20. When echoes of "strong" intensity are located in or near a severe weather forecast area, special observations should be transmitted

(a) when the echoes are first observed, and at regular observation times while they persist.

(b) only when the echoes are first observed.

(c) when the echoes are first observed, at H + 10 each hour, and at regular observation times while the echoes persist.

(d) at the first H + 10 scan after the echoes are first observed.

RADAR OBSERVER QUALIFICATION EXAMINATION

ANSWERS AND REFERENCES TO SAMPLE QUESTIONS

1.	(d)	Weather Radar Manual, Part B,	page	1-1
2.	(b)	Weather Radar Manual, Part B,	page	1-7
3.	(b)	Weather Radar Manual, Part B,	page	1-8
4.	(c)	Weather Radar Manual, Part B,	page	1-9
5.	(a)	Weather Radar Manual, Part B,	page	2-2
6.	(c)	Weather Radar Manual, Part B,	page	3-1
7.	(a)	Weather Radar Manual, Part B,	page	3-2
8.	(c)	Weather Radar Manual, Part B,	page	3-4
9.	(b)	Weather Radar Manual, Part B,	page	3-6
10.	(a)	Weather Radar Manual, Part B,	page	1-8
11.	(c)	Weather Radar Manual, Part B,	page	4-6
12.	(c)	Weather Radar Manual, Part B,	page	5-6
13.	(c)	Weather Radar Manual, Part B,	page	5-20
14.	(d)	Weather Radar Manual, Part B,	page	5-22
15.	(b)	Weather Radar Manual, Part B,	page	11-15
16.	(a)	Weather Radar Manual, Part A,	pages	3 & 12-2
17.	(b)	Weather Radar Manual, Part A,	page	5-3
18.	(c)	Weather Radar Manual, Part A,	page	5-7
19.	(a)	Weather Radar Manual, Part A,	page	10-1
20.	(c)	Weather Radar Manual, Part A,	page	12-1

SECTION IV
RADAR REPORTS

SECTION IV

RADAR REPORTS

SECTION IV

RADAR REPORTS

RH ISSUE NUMBER	TITLE	DATE

FILE WITH SECTION IV, RADAR REPORTS

PREPARATION OF THE RADAR SUMMARY

1. Purpose of the Message.

The radar narrative summary is a widely used product serving both the general public and aviation interests. It is included in continuous radio broadcasts to pilots by the Federal Aviation Administration Flight Service Stations and is given wide public distribution via the mass news media. Many users receive radar narratives prepared by different radar offices and it is desirable to standardize the message format.

2. Writing Style.

The narrative should be written as a news report. That is, it should be concise and factual.

3. Narrative Format.

In the first line, the narrative should state the city location of the Weather Service office issuing the summary followed by the title (Radar Summary or Radar and Precipitation Summary) and date. The time of observation should be included in the body of the message near the beginning. The summary should then describe the location, type, intensity, coverage and movement of precipitation. When feasible, a short trend forecast should be included in the summary.

Especially significant activity should be highlighted in the narrative by placing it first or in a separate lead paragraph.

The location is best described as an area bounded by three or four well-known points or as a band X miles wide centered along a line connecting two or three well-known points. The points should be cities or towns whose locations are generally understood. Using points located at some direction and distance from cities is necessary at times; however, this practice should be minimized, as too many such points make the message difficult for a listener to understand. Locations such as "just north" or "near" can be used in many reports. State names should be used as necessary to more clearly convey the locations. When long lines or large areas are reported, sufficient points should be included so that a listener can readily evaluate the summary in terms of his location.

The intensity of precipitation, other than in thunderstorms, should be specified only as light or heavy. For moderate intensity, simply list the precipitation without the adjective "moderate" since moderate is not well understood by most of the public. Intensity changes may be given when considered significant. When TRW- is the strongest intensity occurring it will be described in the summary as thundershower without an intensity modifier. Distinction of rain showers and thunderstorms and the inclusion of both terms in the summary is not to be routinely made but only if a few thundershowers or thunderstorms are occurring in a large area of rain showers. Otherwise, the summary will state only thundershowers or thunderstorms. The term "thundershower" is not to be used when the same area also contains TRW or greater. In the case of TRW, use the term thunderstorms, for TRW+, use heavy thunderstorms, for TRW++, use very heavy thunderstorms. The terms "intense" and "extreme" should not be used in the narratives. For thunderstorms of very heavy or greater intensity, give the theoretical rainfall rate in in/hr as found in table 5-2, part A, WRM.

The coverage of precipitation in the radar narrative can either be the areal coverage in percent or by the use of the adjectives isolated, few, scattered, numerous, and solid. (See table 1.) Regional headquarters will make the decision on which method they wish their field offices to use. Examples of these ways of describing the coverage in the radar narrative follows.

EXAMPLE 1.

AT 11:45AM LIGHT RAIN COVERS 20 PERCENT OF A 100-MILE WIDE AREA OF CENTRAL TEXAS CENTERED ALONG A LINE FROM LAKE BUCHANAN SOUTHWARD TO CORPUS CHRISTI. THIS PRECIPITATION WAS MOVING TOWARD THE NORTHEAST AT 25 MILES PER HOUR.

TOPS ARE UNIFORM AT 15 THOUSAND FEET.

EXAMPLE 2.

AT 6:40PM HEAVY THUNDERSTORMS COVERED 80 PERCENT OF A LINE 25 MILES WIDE EXTENDING FROM ERIE SOUTHWESTWARD TO ZANESVILLE. STRONG GUSTY WINDS AND HAIL WERE OCCURRING WITH THESE THUNDERSTORMS. THIS LINE OF THUNDERSTORMS WERE MOVING TOWARD THE SOUTHEAST AT 20 MILES PER HOUR AND WERE EXPECTED TO MOVE INTO THE PITTSBURGH AREA BY 8PM.

MAX TOPS 48 THOUSAND FEET.

EXAMPLE 3.

HEAVY THUNDERSTORMS WERE LOCATED 25 MILES SOUTHWEST OF MONETT AT 540 PM. THESE WERE MOVING NORTHEAST AT 45 MILES AN HOUR AND WERE EXPECTED TO MOVE INTO MONETT ABOUT 6 PM AND INTO SPRINGFIELD BY 7 PM. STRONG GUSTY WINDS AND HAIL ARE LIKELY WITH THESE HEAVY THUNDERSTORMS. THESE WERE PART OF LINE OF NUMEROUS THUNDERSTORMS 15 MILES WIDE THAT EXTENDED FROM NEAR OSCEOLA, MISSOURI TO JUST EAST OF JOPLIN TO MCALESTER, OKLAHOMA. THESE THUNDERSTORMS WERE EXPECTED TO MOVE EAST AND BY 7 PM TO EXTEND FROM THE LAKE OF THE OZARKS TO SPRINGFIELD TO FAYETTEVILLE, ARKANSAS TO JUST EAST OF MCALESTER, OKLAHOMA.

MAX TOPS 51 THOUSAND FEET.

EXAMPLE 4.

AT 2:40PM AN AREA OF NUMEROUS THUNDERSTORMS WAS BOUNDED BY A LINE FROM JUST WEST OF OSHKOSH TO NEAR MADISON TO LONE ROCK TO JUST WEST OF OSHKOSH. THE THUNDERSTORMS WERE MOVING NORTHEAST AT 15 MILES PER HOUR AND WERE EXPECTED TO MOVE INTO THE APPLETON AND LAKE WINNEBAGO AREAS BY 4:30PM.

MAX TOPS 35 THOUSAND FEET.

TABLE 1

Adjective	Amount of Area Covered by Echoes
Isolated	less than 5%
Few	5% to 15%
Scattered	16% to 59%
Numerous	60% to 90%
Solid	usually more than 91%

Generally, cell movement will not be given since it is probably not as important as area or line movement and the summaries are not intended to be so detailed. If a particular cell is mentioned because of its significance, its movement should be given. A statement about the intensity tendency and changes in areal coverage may be included. Echo tops data should be on a separate line at the end of the message so that it can be easily recognized and omitted from NOAA Weather Wire transmissions without disturbing the text.

Since the narrative summary pertains to an observation and a forecast made at a particular time and will be broadcast at later times, it should generally be written in the past tense.

Radar observers should always scan sequences and other sources of observational data to stay current on weather conditions in and around the assigned area.

Plotting the observed weather on a 250 mile overlay is an excellent method of determining the extent of precipitation and keeping abreast of changes that occur.

At times the surface observations may show precipitation is occurring in a station's assigned area of radar responsibility which is not being detected by radar. Precipitation that is occurring and not detected by radar should be summarized in very general terms, such as portions of states, well known geographical areas, etc. When this occurs the areal coverage should not be given and precipitation data from surface reports should be so identified. The narrative should state "No precipitation is being detected by radar. However, reports indicate...etc." Precipitation that is occurring and not detected by radar should be summarized in very general terms, such as portions of states, well known geographical areas, etc.

Status reports are not to be included in the weather radar narrative. When the radar is out of service, state "primary radar data not available. However, nearby radars indicate...etc." This type narrative should be stated in very general terms utilizing nearby radar data and/or surface observational data if appropriate. Examples of this type weather radar narrative are as follows.

SOUTHEAST TEXAS...RADAR WEATHER...8:45 AM CST
PRIMARY RADAR DATA NOT AVAILABLE. HOWEVER, NEARBY WEATHER RADARS INDICATE NO PRECIPITATION OVER SOUTHEAST TEXAS AND ADJACENT COASTAL WATERS.

NORTH GEORGIA...RADAR WEATHER...10:45 PM CDT
PRIMARY RADAR DATA NOT AVAILABLE. OTHER WEATHER RADARS INDICATED SCATTERED HEAVY THUNDERSTORMS CONTINUE OVER NORTHWEST GEORGIA. THUNDERSTORMS ARE MOVING TOWARD THE NORTHEAST 35 MPH.

4. Area to be Covered.

The effective range of the radar varies with the type of precipitation being observed. Most convective activity is detectable to a range of 125 nmi; however, precipitation from stratiform clouds, particularly snow, often is not detectable beyond 70 to 80 nmi. The assigned areas for each station are such that precipitation may occur at the more distant ranges and not be presented on the scope. The format allows, and the message should include, reporting of these precipitation areas. All offices are required to prepare summaries out to a range of 125 miles.

Echoes observed beyond an office's assigned area generally should not be summarized. If mentioned because of particular importance, such as when severe weather is associated with them, they should be described in general terms only, because of the limited detection capabilities of the radar at greater ranges.

FILE WITH SECTION IV, RADAR REPORTS

CONVERSION TABLE FOR MILES PER HOUR TO KNOTS

The movement of precipitation is recorded on form MF7-60 and transmitted over the teletype in nautical miles per hour. The movement which is given in the radar narrative is statute miles per hour. The following chart will be useful in converting from nautical miles per hour to statute miles per hour.

1 knot = 1.15155 miles/hr = 0.514791 meters/sec 1 mile/hr = 0.44704 meters/sec

Knots	MPH	MPS	Knots	MPH	MPS
1	1.2	0.5	56	64.5	28.8
2	2.3	1.0	57	65.6	29.3
3	3.5	1.5	58	66.8	29.9
4	4.6	2.1	59	67.9	30.4
5	5.8	2.6	60	69.1	30.9
6	6.9	3.1	61	70.2	31.4
7	8.1	3.6	62	71.4	31.9
8	9.2	4.1	63	72.5	32.4
9	10.4	4.6	64	73.7	32.9
10	11.5	5.1	65	74.9	33.5
11	12.7	5.7	66	76.0	34.0
12	13.8	6.2	67	77.2	34.5
13	15.0	6.7	68	78.3	35.0
14	16.1	7.2	69	79.5	35.5
15	17.3	7.7	70	80.6	36.0
16	18.4	8.2	71	81.8	36.6
17	19.6	8.8	72	82.9	37.1
18	20.7	9.3	73	84.1	37.6
19	21.9	9.8	74	85.2	38.1
20	23.0	10.3	75	86.4	38.6
21	24.2	10.8	76	87.5	39.1
22	25.3	11.3	77	88.7	39.6
23	26.5	11.8	78	89.8	40.2
24	27.6	12.4	79	91.0	40.7
25	28.8	12.9	80	92.1	41.2
26	29.9	13.4	81	93.3	41.7
27	31.1	13.9	82	94.4	42.2
28	32.2	14.4	83	95.6	42.7
29	33.4	14.9	84	96.7	43.2
30	34.5	15.4	85	97.9	43.8
31	35.7	16.0	86	99.0	44.3
32	36.8	16.5	87	100.2	44.8
33	38.0	17.0	88	101.3	45.3
34	39.2	17.5	89	102.5	45.8
35	40.3	18.0	90	103.6	46.3
36	41.5	18.5	91	104.8	46.8
37	42.6	19.0	92	105.9	47.4
38	43.8	19.6	93	107.1	47.9
39	44.9	20.1	94	108.2	48.4
40	46.1	20.6	95	109.4	48.9
41	47.2	21.1	96	110.5	49.4
42	48.4	21.6	97	111.7	49.9
43	49.5	22.2	98	112.9	50.4
44	50.7	22.7	99	114.0	51.0
45	51.8	23.2	100	115.2	51.5
46	53.0	23.7	101	116.3	52.0
47	54.1	24.2	102	117.5	52.5
48	55.3	24.7	103	118.6	53.0
49	56.4	25.2	104	119.8	53.5
50	57.6	25.7	105	120.9	54.1
51	58.7	26.3	106	122.1	54.6
52	59.9	26.8	107	123.2	55.1
53	61.0	27.3	108	124.4	55.6
54	62.2	27.8	109	125.5	56.1
55	63.3	28.3	110	126.7	56.6

FILE WITH SECTION IV, RADAR REPORTS

MANUALLY DIGITIZED RADAR (DR) DATA

PURPOSE OF DR DATA.

The main purposes of DR data are to provide radar data in a form that can be easily communicated and also processed either manually or by computer. An important advantage of DR data is that it greatly facilitates time summarizing (accounting) of hourly observations. These data can be used readily in operational programs such as flood, flash flood, and general forecasting. While this data provides additional radar information to the users, it does not lessen the radar operator's responsibility to notify WSOs, WSFOs, RDOs, and RFCs of significant echoes or activity pertinent to the various warning programs.

PROCEDURE IN OBTAINING DR DATA.

Each WSR-57 radar station in the Central, Eastern, and Southern Regions have been assigned an area, composed of grid squares, for which it will manually digitize the radar data. The grid squares are a subset of the NMC PE grid (1/4 the PE grid length) and are approximately 40 nmi on a side. The grid has been shifted so that a PE grid point lies in the center of a grid square.

Each WSR-57 station will append as a supplement to all regular hourly SD reports a series of digits on a separate line representing the manually-digitized radar information for their assigned area of responsibility. The format for each station will depend upon the configuration of its assigned area. Each series will comprise sets of digits, one for each grid square in their area, ordered in each group from west to east and grouped by rows from north to south (i.e., left to right, top to bottom).

As an example, an assigned area for a particular radar might be configured thus:

	X_1	X_2	X_3	
X_4	X_5	X_6	X_7	X_8
X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_{14}	X_{15}	X_{16}	X_{17}	
		X_{18}		

The appended series of digits would then take the form:

$$\uparrow X_1X_2X_3 \; X_4X_5X_6X_7X_8 \; X_9X_{10}X_{11}X_{12}X_{13} \; X_{14}X_{15}X_{16}X_{17} \; X_{18}$$

These would be placed on the line immediately following the regular SD report. The south arrow at the beginning is for computer use. The east arrow at the end of the previous SD report will be shifted to the end of the new data (see later).

Determination of the proper digits will be with the overlays provided and code table below. Zero will be encoded for each square having no echoes, and/or with echoes but precipitation not reaching the ground. No encoding need be done for PPINE, OM situations. The encoded message should not be placed on the radar observation form, but on the sheets provided, which are already spaced appropriate to the assigned grid squares of each office. The completed forms should be mailed to the appropriate regional headquarters each Monday for the week ending with the last observation on Sunday (GMT). Requests for additional forms should also be sent to the appropriate regional headquarters.

MANUALLY-DIGITIZED RADAR DATA (DR) CODE

Code No.	Maximum Observer VIP Level	Coverage in Box	Rainfall Rate in/hr	Intensity Category
0	NO ECHOES			
1	1	Any VIP1	≤ .1	Weak
2	2	≤ ½ of VIP2	.1-.5	Moderate
3	2	> ½ of VIP2		
4	3	≤ ½ of VIP3	.5-1	Strong
5	3	> ½ of VIP3		
6	4	≤ ½ of VIP3 and 4	1-2	Very Strong
7	4	> ½ of VIP3 and 4		
8	5 or 6	≤ ½ of VIP3, 4, 5 and 6	> 2	Intense or Extreme
9	5 or 6	> ½ of VIP3, 4, 5 and 6	> 2	Intense or Extreme

(Ignore additional coverage by weak echoes for all DR Code numbers above 1. Intensity categories and rainfall rates corresponds to maximum observed VIP levels.)

Information on line echoes and severe storm criteria will be handled by adding, as appropriate, an additional data group at the end of the line by DR data in the teletype message, using the following code: 1) a plus (+) precedes line and column numbers of boxes containing echoes which currently satisfy the ROML criteria for severe convective storms; 2) a minus (-) precedes line and column numbers of boxes which had echoes requiring a special radar observation in the past hour, provided the box does not meet the criteria for a plus sign; 3) a solidus (/) precedes line and column number of boxes which contain echoes which satisfy the WRM criteria for line echoes, provided the box does not meet the criteria for either a plus or minus sign.

lines

Sample message: ↑001 3821 2431 34101 +22/32-41/42←

Severe WX

Special

Note that the message begins with a south arrow and ends with an east arrow. The order of the additive data is from left to right of the basic message, with one space before the additive data and none before the final arrow. There is also one space between groups of the basic message. Of course, very few messages would have the amount of additive data given in this sample.

PROCEDURE FOR VIP STATIONS.

125-mile range:

1. Outline on the PPI those echoes of intensity corresponding to VIP levels 1, 2, 3, and 4, 5, 6 (according to change 4, WRM, January 73).

2. Place the 125-mile acetate grid overlay over the PPI and record on the form provided appropriate digits to describe echo characteristics in each block.

250-mile range (if assigned station area contains grid squares not entirely within 125-mile range):

3. Place the 250-mile grid overlay over the PPI and determine which echoes fall within those assigned squares not covered with the 125-mile range.

4. Remove the overlay and contour the echoes of concern using as intensity thresholds the categories: weak, moderate, strong, and intense. (The Rainfall-Rate Echo Intensity Chart may be used for this purpose.) This is to be done even though the range exceeds 125 miles.

5. Return the 250-mile grid overlay to the PPI and record the appropriate digits to complete the supplemental observation.

PROCEDURE FOR NON-VIP STATIONS.

125-mile range:

1. Contour all echoes using as intensity thresholds the categories: weak, moderate, strong, and intense (according to change 4, WRM, January 73).

2. Place the 125-mile grid overlay over the PPI and record on the form provided appropriate digits to describe echo characteristics in each block.

250-mile range (if assigned station area contains grid squares not entirely within 125-mile range):

SAME AS FOR VIP STATIONS

USE OF DR DATA.

In order to make use of the DR data, each office having county warning responsibility (other as they desire) should have a map of their warning area and the DR block assignments. Maps with DR block assignments can be obtained from the appropriate regional headquarters. Over this map place a piece of transparent acetate. The DR values can then be written on the acetate and wiped clean when more space is needed. The method of entry is as follows:

	00112 32111 1	11312 21100 1	
00111 22111 1	12335 65621 1	12224 43211 2	21101 12111 1
12112 13111 1	11223 23112 1	00113 73111 0	00011 11010 0
	01112 12100 0	00011 11000 0	00010 10110 0

Flash flood potential

The numbers in each box are hourly values, with time running from left to right and top to bottom (11 hours are shown). When all rows are filled, all but the last row can be wiped out so as to start over again. The last row is retained until the first row is complete, thus allowing several hours of past data to exist at all times. The additive data, +, -, or /, can be superimposed on the numbers, preferably in another color. The above procedure will be necessary only until the planned material is available on request/reply.

The prime use of the data is as an alerting device, and more definitive information will be necessary, or at least desirable, before issuing warnings. The data alert one for both severe storms and flash floods. The severe storm alert comes mainly from the additive data, although the figures in the basic code provide additional alerting, especially through trends. If the data indicate or threaten severe weather, and the radar office preparing the data has not already called, a call to the radar office is in order.

For flash floods, past experience suggests that when the sum of the digits for no more than a 4-hour period is 20 or more, there is definite flood potential, and when 24 or more, a flash flood is likely. Increased runoff can be expected in hilly terrain or with the ground soggy from recent rains so somewhat lower values would then give a threat, possibly as low as 12 units. Also, the antecedent conditions can be evaluated through the "Flash Flood - Headwater Crest Stage Guidance" put out by the regional RFCs on Monday and Thursday evening (other times also as needed) which gives the amount of rain needed to produce a flood on particular streams. This information together with the rainfall rates in the code table herein will give alerting clues. If an office sees a threat, it should contact the radar office responsible for the area of concern to ascertain whether or not a real threat exists and what action should be taken.

The radar operator is likely to be well on top of the severe storm problem and the first call about a situation may well be from the radar office. The flash flood problem is more difficult for the radar operator, since his area of concern is most likely larger than that of a WSO, so the radar operator can use the help of the WSO in watching flash flood buildup, especially as it relates to the flash flood guidance of the river centers.

<u>CAUTION</u>: The flash flood problem is a difficult one, for even if one knew how much rain actually fell (one does not usually know this in real time) and exactly where it fell (this is uncertain too) it is still an uncertain step to a flash flood. However, the river forecast center flash flood guidance, plus the radar operator's information and judgment on the rainfall is the way to approach the solution.

SECTION V
RADARSCOPE PHOTOGRAPHY

SECTION V

RADARSCOPE PHOTOGRAPHY

WSH ISSUE NUMBER	TITLE	DATE
1-WSH	CAMERA SYSTEMS FOR WSR-57 RADARS	10/73
2-WSH	POLICY AND PROCEDURE TO PROCURE COPIES OF RADARSCOPE FILM	10/73
3-WSH	PHOTOGRAPHY AT ARTCC SITES	10/73

SECTION V

RADARSCOPE PHOTOGRAPHY

RH ISSUE NUMBER	TITLE	DATE

FILE WITH SECTION V, RADARSCOPE PHOTOGRAPHY

CAMERA SYSTEMS FOR WSR-57 RADARS

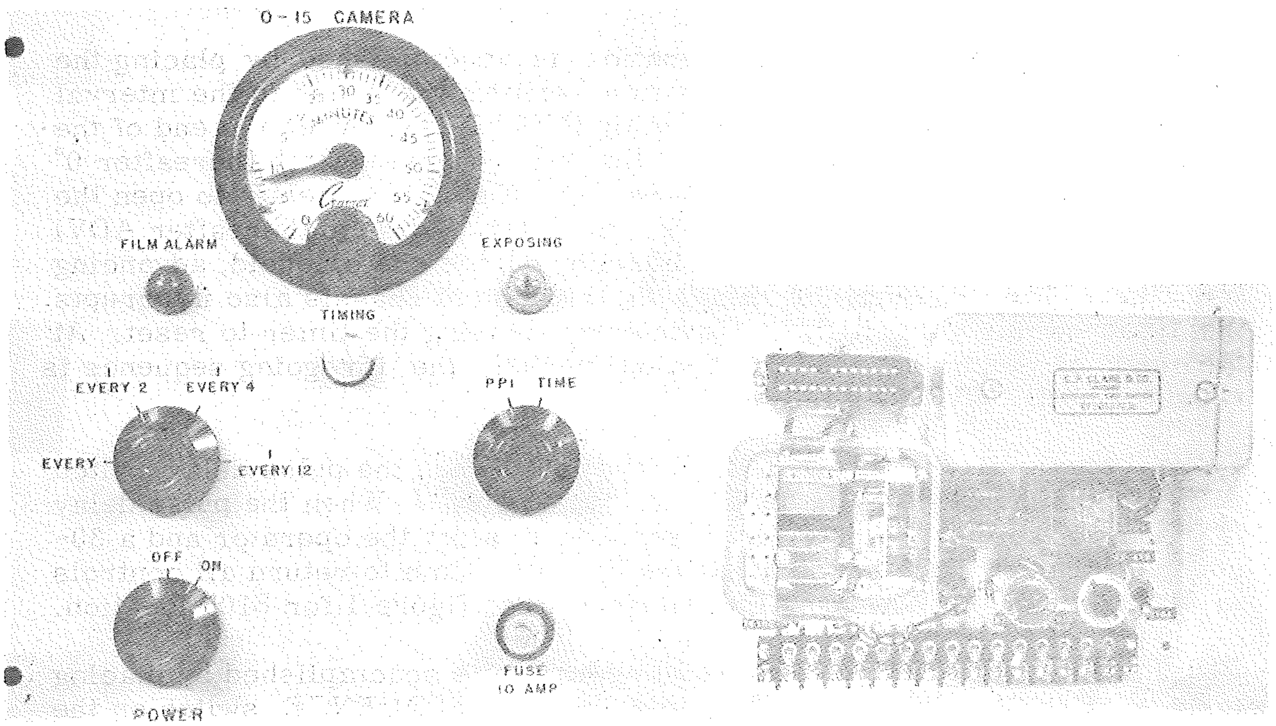

Figure 1. 0-15 camera controls and chassis

0-15 PULSE CAMERA SYSTEM.

General. The 0-15 type pulse camera system as modified for use with the WSR-57 and WSR-57M radar, consists of the following:

(1) 0-15 camera.

(2) 0-15 camera magazine.

(3) Camera hood and radar function relay box.

(4) Exposure frequency control with d.c. power supplies.

The system is designed to take 35 mm pictures of the PPI display and its radar function data indicators. The system is automatically operated. The cameras may be used to make sequence exposures of EVERY (special programs only), 1 EVERY 2, 1 EVERY 4, or 1 EVERY 12 antenna revolutions; or it may be used for preset TIME interval exposures for one antenna rotation. See figure 1 for control location.

Time Programming. Timed operation is accomplished by placing the PPI-TIME switch in its TIME position, setting the timer to the interval desired between exposures, and turning POWER ON. After the end of the preset time, the first pulse from the zero degree switch (hereafter 0° switch) causes the Exposure (hereafter the EXP) relay to open the shutter and closes the contacts to the Film Advance (hereafter ADV) solenoid. The second 0° switch closure pulses the solenoid, advancing the film. The sequence of relays in the control chassis also interrupts the timer motor circuit during exposure, causing the timer to reset. At the end of each succeeding timing period, the foregoing sequence is repeated until POWER is turned OFF.

Pulse Delay. A PULSE DELAY is available when the pulse delay switch S105 on the pulse chassis is ON at "timed out."[1] When the pulse delay is used, a buzzer sounds for 2 seconds to alert the operator and a 30-second delay of the 0° pulse gives the operator time to return all controls to standard settings before the exposure. See figure 1 for S105 location.

PPI Programming. PPI (sequence) operation is accomplished by placing the PPI-TIMER switch on PPI, placing the SEQUENCE switch on the desired program and turning POWER ON. The EVERY position of the sequence switch has been disconnected except for special projects at selected stations. When connected, the capping shutter remains open and each antenna 0° pulse closes an inner shutter and advances the film. In the 1 EVERY 2 position, the first pulse from the radar antenna 0° switch will advance the sequence switch and open the shutter. The next pulse close the shutter as the film advances. The third pulse will again open the shutter and so on. An exposure is made during every other antenna revolution. In the 1 EVERY 4 position, the first two 0° switch pulses have no effect on the camera. The third pulse opens the shutter. The fourth closes the shutter and advances the film. An exposure is made every fourth antenna revolution. In the 1 EVERY 12 position, the first 10 pulses have no effect, the 11th pulse opens the shutter and the 12th closes the shutter and advances the film. An exposure is made every 12th revolution of the antenna.

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[1] "timed out" is the timer switch condition of the electrical connection at the end of the present time period.

Film Alarm. The 100-ft magazine has an alarm switch that will energize the buzzer when the film does not advance for three to five frames, or when only 5 ft of film remains in the magazine. The alarm will continue until power is turned off, the magazine contact is shorted to ground, or a new magazine is installed and programmed two or three times.

Internal Data Lamps. Adjustment of the camera data chamber lamps is accomplished by adjusting R101 on the 0-15 control chassis. Normal dial setting is 3; however, it should be adjusted based on the test strip or film review. See figure 1 for R101 location.

POLAROID CAMERA SYSTEM.

General. The Polaroid camera system consists of the following:

(1) Polaroid camera, electrically modified for RPPI.

(2) Camera Hood with beam-splitter mirror and radar function relay box (shared with 0-15 type pulse camera).

(3) Exposure frequency control with d.c. power supplies.

The system is designed to take Polaroid pictures of the repeater display and radar function indicators. Single exposures may be taken manually or automatically at preset intervals. Multiple exposures (to obtain integrated photographs) may also be programmed. Each exposure is for the duration of one antenna rotation. There is no provision for recording date, time, counter, or data card. See figure 2 for control location.

Polaroid Timing. This control consists essentially of two stepping switches and an interval timer, designed to open the shutter of the Polaroid camera for one revolution of the antenna at time intervals of pre-determined length for single or multiple exposures. The clock timer can be set for any desired time interval from 2 to 60 minutes. The EXPOSURES switch marked from 1 through 10 and infinity determine the number of exposures that will be made during a program. The FUNCTION switch marked 1X and 3X is a multiplier. For example, if the clock timer is adjusted to 5 minutes, the exposure is set on 4, and the function switch set on 3X, the following sequence of events will occur:

NOTE: The camera shutter must be on "B" or Bulb position.

(1) When the Polaroid camera power is turned ON, the clock timer will start and the TIMING light is energized.

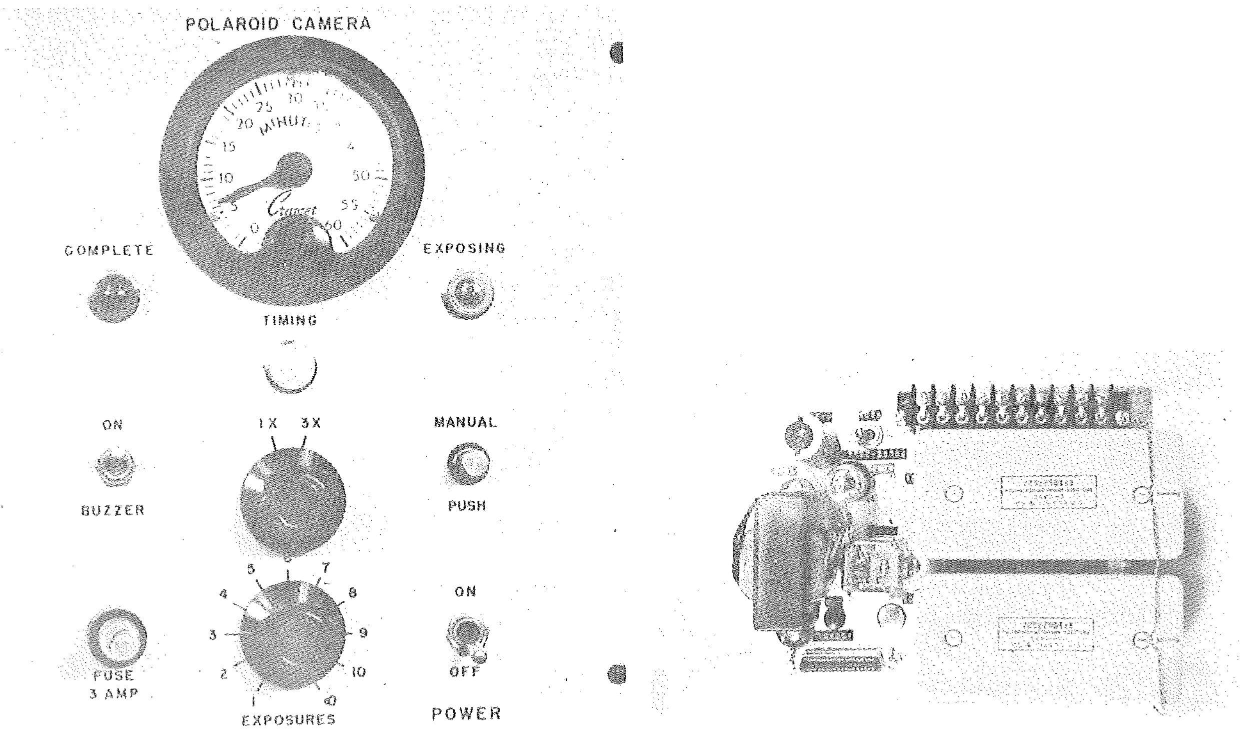


Figure 2. Polaroid camera controls and chassis

(2) At the end of 5 minutes, the timer resets, the TIMING light goes off, and the circuit is ready for the closing of the 0° switch.

(a) When the PULSE DELAY switch (S407 of figure 2) is ON, a buzzer sounds for 3 seconds to alert the observer to "timed out." A 30-second delay on the 0° pulse gives the observer time to return the radar controls to standard settings before the exposure.

(3) When the antenna switch closes momentarily at 0° azimuth, the camera solenoid is energized opening the shutter, and the EXPOSING light is energized.

(4) When the antenna comes around again to the 0° azimuth position the antenna switch closes momentarily, closing the shutter and activating the clock timer and TIMING light.

(5) The foregoing cycle is repeated for a number of times depending on the setting of the EXPOSURES and FUNCTION switches (in this instance 4 x 3, or a total of 12 times) at which time the COMPLETED light is energized and the buzzer alarm sounds, indicating the end of the program.

The buzzer and COMPLETED light will remain energized until the power switch is turned off. When the power is again turned on, the program will repeat itself. A single exposure can be made at any time by pressing the MANUAL switch. The exposure is complete (one revolution of the antenna) when the EXPOSING lamp goes off.

NOTE: With the rotary selector (EXPOSURES) switch in the infinity position, the exposing sequence will continue indefinitely. This position is for maintenance tests only.

Polaroid Manual Operation. A single exposure may be made by pressing the MANUAL switch. With controls set for 2 to 60 minutes, IX, 1, Pulse Delay OFF, and POWER ON, the following occurs:

(1) When the 0° antenna switch pulses the control, the camera solenoid opens the shutter and the EXPOSING light shows.

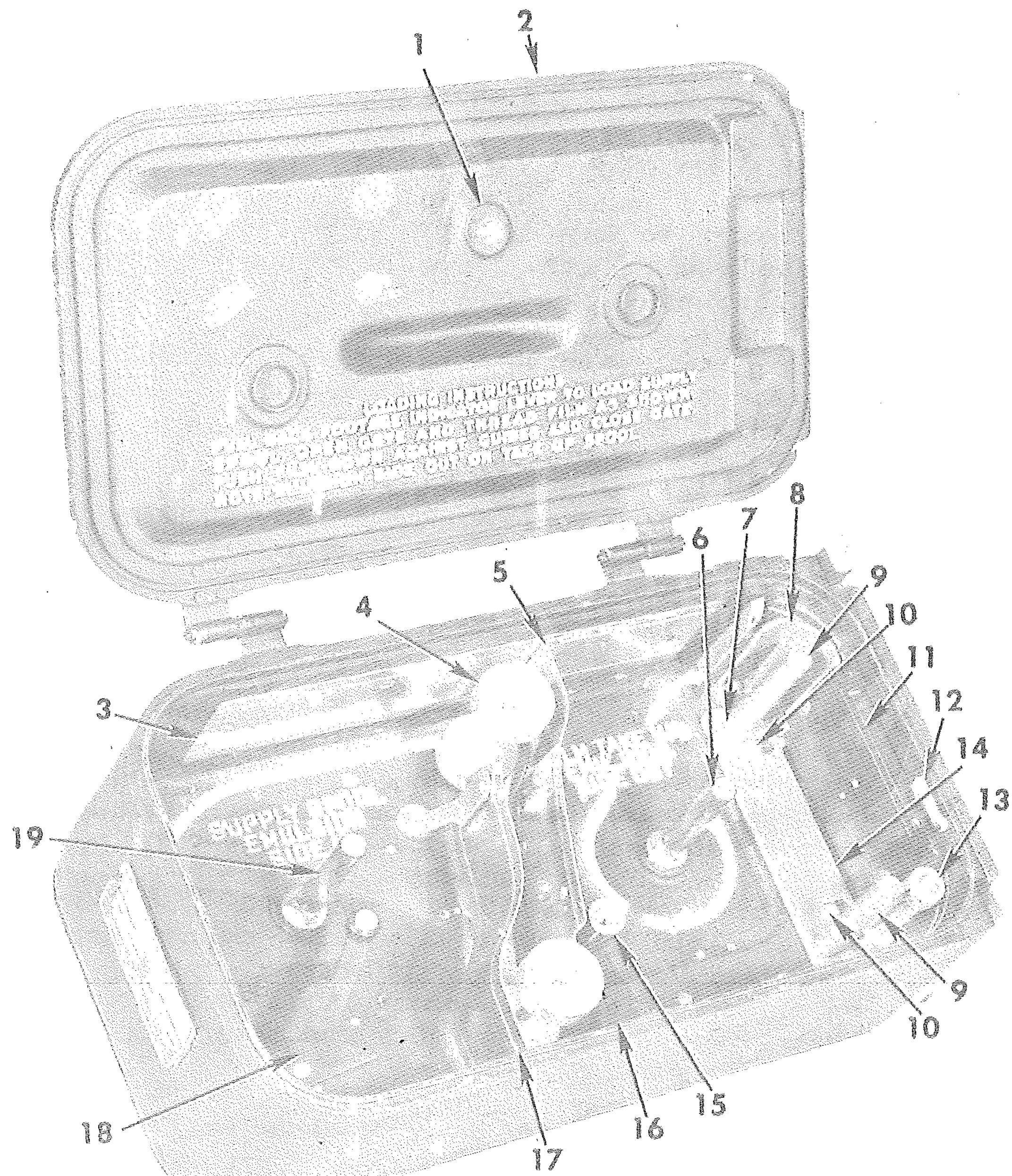
(2) The next 0° antenna switch pulse ends the film exposure, de-energizes the exposure indicator lamp, and energized the completed light and buzzer.

CAUTION: When single MANUAL exposures are made and the controls are set at other than the "1X" and "1" position, or the control has been operated in the INFINITY position, or if the film is removed from the camera and the control turned off before the present number of exposures has been made, the following action must be taken to reset the control: (Put the FUNCTION switch on "1X" and turn the POWER ON). Rotate the EXPOSURES switch counterclockwise, then clockwise slowly until buzzer sounds. When the alarm sounds, allow 1 second before turning the POWER OFF so the stepping switches can return to the "Home" or ready position.

After this has been accomplished, the control is ready for automatic operation and will remain so as long as normal programs are completed. ALWAYS complete a program (automatic or manual) before turning the power off.

FILM HANDLING.

NOTE: HANDLE UNPROCESSED FILM UNDER SUBDUED LIGHT CONDITIONS ONLY. KEEP THE FILM WOUND TIGHTLY AROUND THE FEED OR TAKEUP SPOOL TO KEEP THE AMOUNT OF FILM EXPOSED TO A MINIMUM.



Key	Description	Key	Description
1	Cover Locking Knob	11	Film Gate Assembly
2	Film Chamber Cover	12	Gate Lock
3	Film Upper Shield	13	Film Roller
4	Rocker Rollers Assembly	14	Gate Mounting Plate
5	Takeup Baffle Assembly	15	Cover Locking Post
6	Film Spool Post (Takeup)	16	Film Lower Shield
7	Plate and Gate Assembly	17	Feed Baffle Assembly
8	Film Takeup Cup	18	Footage Arm A
9	Locating Pin	19	Film Spool Post (Supply)
10	Lock Pin		

Figure 3. 0-15 camera film magazine

Film Storage. The film should be stored in a cold, dry place in order to prolong its useful life. Generally, film stored in a refrigerator should last several months beyond the expiration date of the film. Film stored in air conditioned rooms, such as the radar room, should keep satisfactorily. It is important that the film be kept sealed in its original wrapper during the time it is stored. The film should be removed from the refrigerator several hours before it is to be used so that it will reach room temperature before being removed from the wrapper. This will prevent damage from condensation.

0-15 CAMERA MAGAZINE FILM.

Film Type and Characteristics. Plus-X 35 mm negative film in 100-ft rolls is normally used. This film has proper speed, phosphor response, and definition for radar scope photography. Each station will maintain a sufficient supply of film, especially before the local severe storm and hurricane season.

0-15 Camera Magazine Loading. Accomplish in near darkness or, preferably, use a film loading bag.

(1) Place the magazine in the position shown in figure 3.

(2) Unscrew cover locking knob (1) and open the film chamber cover (2) away from the operator, as shown in figure 3.

(3) With a finger, pull the film footage dial arm (20) all the way back against the bottom of magazine body to allow placement of the film supply spool on post (21).

(4) The supply spool must be placed so its square hole seats over the square collar at the base of the film spool past (21), so it will unreel clockwise when the magazine is placed as shown in the figure.

(5) Unroll about 1 1/2 to 2 ft of film for insertion in the film channels and to connect to the takeup spool. Thread the film clockwise around the film roller (4), then advance the leader in an "S" direction and proceed counterclockwise around the other film roller. Advance the leader along the lower shield (18).

(6) Pull the gate lock (12) upward releasing the film gate (11) which will then spring open.

(7) Advance the film leader around the film roller (13) and then between the film gate (11) and the magazine body, being certain that the film leader is pushed all the way down so its lower edge is against the two film guide studs.

(8) Proceed around the film takeup cup (8) and then insert the end of the leader into the slit in the shaft of the film takeup spool mounted on the post (6).

(9) Again, push the film leader all the way down edgewise so that its lower edge is against the two film guide studs.

(10) Close the film gate (11) and lock it in place with the gate lock (12).

(11) With a finger, revolve the film takeup spool counterclockwise just enough to take up the slack in the leader.

(12) The correct threading of the leader can be checked by observing the directional arrows on the bottom of the film chamber.

(13) Close the film chamber cover (2) and lock it by turning the cover locking knob (1) until it is finger tight.

(14) Using the telltale indicator knob on the side of the magazine opposite the film chamber cover, advance approximately 4 ft of film (count 5 revolutions of the supply spool knob). This will provide a leader of proper length and insure that unspoiled film is in position for initial data collection. This procedure advances any film that might be exposed as a result of daylight loading.

(15) Release the end cover (engage upon the side of the magazine) by pulling upward on the ends of the end cover strap. Cover the front end of the magazine by pressing the end cover pins into corresponding holes in the locking bars in order to protect the mating surfaces of the magazine.

(16) When the magazine is not in use, an end cover should be installed to prevent possible damage.

Film Monitoring.

(1) About 5 to 6 ft of film is allowed at each end of the film roll for a leader and trailer. Leaders and trailers help to protect interior film from light during loading and unloading operations and are necessary to facilitate installation of film in the processing and viewing equipment.

(2) Use the following relationships to measure and monitor film usage:

(a) One turn of a full spool equals 10 inches of film.

(b) "100 ft" Plus X film rolls contain precisely 113 feet of film.

(c) There are 16.1 frames per foot of film.

(d) Note the reading of the 0-15 frame counters when a new roll of film is started. Attach a note or tag to the magazine to indicate initial reading and initial reading plus 1600. Monitor the frame counters to anticipate changing film when 1600 to 1650 frames (99 to 102 feet) have been exposed (not counting leader). Within these limits it will usually be possible to avoid changing magazines during a significant weather event. (Note: The note or tag mentioned above should indicate which of the two frame counters to monitor since there may be a difference in their initial readings).

(e) After 1600 to 1650 frames have been used, remove the magazine from the camera and advance all the film onto the takeup spool before opening the magazine cover.

(3) The present film trouble system of the 0-15 camera alarm is designed to trigger the buzzer and warning light when there have been three to five exposure pulses without a corresponding film advance sequence. All personnel required to operate the radar should ask a qualified electronics technician to demonstrate the resetting procedure for the film trouble alarm. The alarm system can be reset by shorting the contact button on the back of the camera to the camera body, by depressing the top of the reset coil (after removing the dust cover), or by mounting another magazine and operating the camera for one, two or three cycles.

Film Unloading. When the film alarm sounds, the counter and the footage indicator shows 10 or less feet to end of film, or the film becomes jammed, the following procedures should be performed.

(1) Remove the magazine.

(2) Advance the film manually. To advance the film manually when loading or unloading the C-1A camera magazine, perform the following operations in very subdued light with the magazine cover closed.

(a) To release the film holding blade, use a finger to hold the sector arm (lever recessed in magazine face) at least one-half way.

(b) Rotate the film takeup spool knob clockwise. When it turns hard, rotate the feed spool knob counterclockwise one-half turn or more and pump the sector arm occasionally.

NOTE: The film footage dial arm (20) must be pulled back with a finger all the way against the bottom of the magazine body to remove the film supply spool. When a magazine becomes jammed, use a room that is absolutely dark or a changing bag to keep from exposing the film. If the jamming occurs near the end of the film, roll the remaining film onto the takeup spool. To salvage the exposed film in a jammed magazine, wind up all the exposed film plus a protective trailer. Open the magazine only in absolute darkness if necessary to allow the film to be wound. If well over one-half the amount of unexposed film remains, transfer the film and spools to another magazine without rolling or unrolling the film. To avoid losing any exposed film, place the takeup spool in the new magazine and thread the film toward the supply spool. After the cover is closed, wind at least five more turns of film to eliminate taking pictures on the transfer-exposed section of film. If the exposed film will be lost in this process, do not reload the film, but wind it up on the takeup spool. Secure the trailer around the roll with rubber bands or with the manufacturer's original paper band, then transfer the roll promptly to a film can and seal the can with masking tape. Do not use transparent tape or the fabric-base tape that originally sealed the can. After the transfer has been completed, forward the film to NCC.

Film Processing. Completed film rolls should be forwarded immediately to the National Climatic Center for processing. NWS Form B-10 should be filled in completely and pasted on the film box. The "Remarks" section of Form B-10 should contain notes that will help the film editor evaluate the film.

(1) When a station desires a copy of its time-laps film for local research studies or training purposes, they should request it from NCC, at the time the exposed film is sent in for processing. However, because of the cost of reproduction and local storage problems, only those films that are necessary for a specific purpose should be requisitioned.

(2) Local procedures should be established for keeping track of all film sent to NCC as well as cataloging and filing any film (Polaroid and time-lapse) retained at the station.

POLAROID CAMERA FILM.

Film Types and Characteristics. Three types of Polaroid film are used in radar photography. These are as follows: (1) print type 47, ASA3000, (2) a very high-speed paper type 410, ASA 10,000 (for A-scope photography), (3) type 46L, ASA 1000 daylight, 700 tungsten transparency film. Type 47 is developed for 10 seconds. The type 46L is developed for 2 minutes and then dipped into a hardening solution (Dippit) to protect the transparency. It is possible to write any pertinent data desired on this transparency before the hardening solution is used. Care must be taken, however, to avoid touching the film with the fingers before hardening. Transparency film will be used in the dual camera hood Polaroid; paper film is not suitable because the beam-splitter mirror reverses the image position.

(1) The transparency film that can be enlarged by a projector is especially well suited to hydrology, climatology or research studies, lectures, training programs, and any other purpose which would involve viewing of the photo by a group.

(2) One use that can be made of the Polaroid camera is obtaining photo-integrations of the radar echoes for precipitation analysis. Discussion of this subject is fully covered in part B, chapter 11, Radar Hydrology, of the Weather Radar Manual. A prime use is single exposure of unusual or severe weather phenomena.

(3) Since the type 47 film is so much faster than the type 46L film, it permits the use of a higher f-stop when photographing and insures a sharper and clearer picture.

Polaroid Camera Film Handling. Loading, unloading, and processing: Step-by-step loading and picture removal instructions for this camera can be found on the back of the camera and on the film leader.

Polaroid photographs should be handled with great care at all times and particularly during processing when the emulsion is soft. The manufacturer's instructions for "Dippit" processing and drying of transparencies and for coating of prints should be strictly adhered to. A row of hooks or nails spaced 3 inches apart on the underside of a shelf or on a wall will be helpful in preventing accidental damage to prints and transparencies while they are drying. Transparencies, in particular, should be allowed to dry and harden for several hours before being filed. During this time they should be kept in proper sequence and protected by being hung from the hooks by means of spring clips (item 2 in the following materials list) attached to the margin. A second clip should be used as a weight on the other end of the transparency to prevent excessive curling. When a transparency is framed for projection, the proper size frame should be used, otherwise the transparency is almost certain to be damaged. Early types of 46L transparency film required a No. 632 frame but later and current supplies require the smaller No. 633 frame. Occasionally a transparency is damaged in being removed from the camera. This type of damage can be avoided by pulling the transparency from the film roll in a smooth, diagonal motion.

Polaroid Film Classification and Filing. Development of an adequate system for handling Polaroid photographs is recommended. Photographs should be properly exposed, free of stains or scratches, and well-documented. When properly used, Polaroid prints and transparencies can be a valuable tool in radar operations and research. A well-maintained Polaroid file will prove to be useful for many purposes: as a data source for local studies, for training, for illustrations in published papers, for aircraft accident investigations, and as a back-up for time-lapse photography. The print shall be coated with preservation as soon as it is removed from the camera to prevent scratches or finger marks from marring the emulsion. Before the preservative has dried, a serial number, the station call letters, date and time of exposure, f-stop setting, range in nautical miles between markers, degrees of antenna tilt, and coded data (as in table 2) or abbreviations, as necessary, shall be written on the back of the photograph. Transparencies should be processed in accordance with instructions furnished with Dippit kit. The above data and additional information will be entered on a local form when a photograph is taken.

A complete classification and filing system is outlined below. Its adoption is suggested at each WSR-57 station unless a completely satisfactory system is already in use. Material required is listed in table 1.

Convert the record book (7) to a Polaroid logbook by arranging left-hand pages into columns. Column headings should provide for essential information on radar parameters and for identification and classification. Examples of column headings are: serial number, date, time, range, pulse length, STC (on or off), azimuth (for RHI), attenuation, classification. The classification column should be wide enough to permit several classification code entries. It may be helpful to provide a column to indicate by a check mark when the classification code entries have been posted to the card index (8). A copy of the classification code may be attached inside the front cover of the logbook for convenient reference. Right-hand pages should be reserved for remarks and additional documentation. Logbook entries should provide for rather complete identification and description without the necessity of referring to the photograph itself.

Table 1. Material required for Polaroid classification system

Reference no.	Item	Federal stock no.	Quantity
(1)	Filing case, 3 x 5 x 10 in.	7520-286-6957	1
(2)	Binder clip, large	7510-223-6809	24
(3)	Stylus	7520-238-3502	1
(4)	Guide cards, (blue) 3 x 5 in., 1/5 cut	7530-261-3803	300
(5)	Guide cards, (buff) 3 x 5 in., 1/5 cut	7530-261-3804	300
(6)	Guide cards, (salmon) 3 x 5 in., 1/5 cut	7530-261-3805	100
(7)	Record book, 8 x 10 1/2 in.,	7530-222-3525	1
(8)	Index card box, 3 x 5 in.	7520-234-6356	1
(9)	Index cards, 3 x 5 in.	7530-247-0325	100

The following classification code is suggested. Operational programs, geographical and climatological locations might require further changes before adoption at a particular station.

Table 2. Classification code for Polaroid photographs

A. Attach a letter-suffix to the serial number to indicate type of photograph:

RHI.................R
Sequence.............S
Integration...........M

B. Select and enter in the log all applicable code designations from the table below. Also enter additional amplifying remarks as needed to adequately describe the significant subject matter of the photograph.

A1	Aircraft	N1	Notch
A2	Aircraft emergency		
A3	Angel	O1	Offshore (80% or more of echoes)
A4	Anomalous propagation	O2	Overland (80% or more of echoes)
A5	Altitude 40,000 ft or more	O3	Overrunning precipitation
B1	Banded structure	P1	Persisting echo
B2	Birds		
B3	Bright band	R1	Rain shield
C1	Chaff	S1	Sea return
C2	Circulation	S2	Spiral band
C3	Clear-air turbulence	S3	Stratiform
		S4	Showers, diurnal
E1	Easterly wave	S5	Showers, marine
E2	Echoes aloft	S6	Showers, air mass
		S7	Snow
F1	Fine line		
F2	Front, cold	T1	Thunderstorm
F3	Front, warm or stationary	T2	Thunderstorm, severe
F4	Funnel	T3	Tornado
		T4	Trough
H1	Hail		
H2	Hole	U1	UFO (unidentified flying object)
H3	Hook	U2	Unusual distribution pattern
H4	Hurricane, tropical storm	U3	Unusual echo configuration
I1	Instability line	V1	Verification record available
I2	Interference	V2	Vertical wind shear
L1	Large rain area	W1	Waterspout
L2	Lee wave	W2	Wave
L3	LEWP (line echo wave pattern)		
L4	Lightning (sferics)	X1	Synoptic, 0000 GMT
		X2	Synoptic, 0600 GMT
M1	Mesolow	X3	Synoptic, 1200 GMT
M2	Mixed precip. (frozen & liquid)	X4	Synoptic, 1800 GMT

A serial number is assigned to each photograph. Certain special types of photographs are further identified by a letter-suffix attached to the serial number. The serial number can be written on the back of each Polaroid print or inserted in the margin. The most satisfactory method of writing the serial number on transparencies is to "reverse-write" the number on an unused area of the emulsion side. This should be done at either of two stages by using a sharpened steel stylus (3). The first occasion when this can be done is immediately after removing the transparency from the camera. The second opportunity occurs between 30 min and about 1 hr after the Dippit process. At other times the results are likely to be illegible because of either the emulsion peeling or becoming too hard to be marked easily. After they are thoroughly dry, all photographs can be filed serially in the filing case (1) interleaved with guide cards of matching numbers (4), (5). Alternate colors of guide cards are arranged in groups of 100. Individual envelopes are not required.

Access to the Polaroid data is provided by the card index (8) and the logbook. Index cards (9) are arranged with guide cards (6). Each classification code is represented in the card index by a guide card and at least one index card. Periodically, perhaps weekly, posting from the logbook to the card index should be done by typing appropriate serial numbers in lines or columns on the matching index card. As an example of how the system might work, suppose one wishes to locate one or more examples of hooked echoes where the photographs were made with the radar operating in short pulse mode. The H3 classification in the card index will list the serial numbers of all photographs of hooked echoes. Checking these serial numbers in the logbook will then provide a description of each hooked echo photograph and the "Remarks" column will indicate those photographs taken in short pulse mode. The accompanying descriptions can be used to select a desired example or else the entire sub-class, hooked echoes-short pulse, can be located in the serial file.

RADAR PHOTOGRAPHIC REQUIREMENTS.

<u>General.</u> Instruction Manuals, Quality Control Memoranda and experience will help determine the proper settings for controls on the operator's console and repeater scopes. After optimum control settings have been determined, they should not be changed indiscriminately. The foregoing does not preclude operation at different settings to meet local requirements, but these changes should be kept to a minimum.

<u>Radar and Camera Controls.</u> See section 3, volume 1 of the WSR-57 or WSR-57M Radar Manuals for radar PPI controls. Additional controls affecting photographic exposure are: Camera aperture (f-stop), hood lamp intensity, and 0-15 camera data chamber lamps.

CAUTION: The antenna should not be stopped on the 0° position for 1 or more minutes, as damage to a film alarm reset solenoid may result.

Adjust the selector switch on the camera control unit to yield the required rate of picture taking. In any case, pictures should be taken at uniform intervals. A lens aperture of f-5.6 or f-8 is recommended for both the 0-15 and the Polaroid cameras when using Plus X and type 46L film.

Lighting. A Polaroid camera can be used to determine exposure settings experimentally. The exposure setting problem involves four types of light sources: echoes, range marks, fixed brightness data lights, and variable brightness data lights. Satisfactory results require balancing the different light sources and selecting the aperture (f-stop) appropriate to the film speed. Scope intensity should not be regarded as a variable. It can be shown that there is only one intensity setting at each range for optimum results in normal use. The intensity control should be set so that the rotating sweep is barely visible without receiver or video gain. The optimum intensity setting differs for different ranges due to a change in writing speed. After the intensity control is set, standard IF gain should be set and the video gain should be adjusted for maximum contrast without "blooming." Selection of the aperture setting and final adjustment of the video gain should be determined on the basis of the photographic results. A small amount of scope background lighting is acceptable in order to insure the depiction of weak echoes. To interpret echoes in terms of intensity, it is important that such factors or scope intensity or brilliance and the "f" setting on the camera not be adjusted or changed during the exposure period. If it is necessary, a notation to this effect should be made on the data card and on the operation form.

Range Mark Intensity. The range markers on the repeater scopes should be adjusted so they have the same intensity as the echoes or ground clutter targets. Range is generally set to the minimum range that will encompass all echoes concerned, except periodically when severe or unusual weather is expected or observed.

Radar Scope Focus. Scope focus may require adjusting from time to time to insure sharpness of the echoes being photographed.

Sensitivity Time Control. STC on the WSR-57 should be used when photographing to approximate range normalization.

Camera Lens and Scope Care. Keep the camera lenses and scope faces clean. Be careful of fingerprints from careless handling. A camel's hair brush should be used for removing dust from the lens surface, and lens tissue for removing smears or fingerprints. Do not use coated or treated lens tissue.

McGill Filters. The quality of radarscope photography depends largely on adjusting the various light sources so that they are (1) balanced and (2) within the intensity range appropriate to the film in use. Unless corrected by some means, all PPI type displays are characteristically much brighter in the center than at the edge due to sweep spacing. Radar meteorologists at McGill University have developed a simple and economical means of making the correction using a variable density filter.

The filter should be trimmed concentrically to a diameter of 7 inches to fit within the recessed flange of the azimuth ring of the WSR-57 photo-repeater. After installation, make certain that the airstream from the ventilation system does not dislodge the filter. Small tabs of transparent tape may be used to secure the filter.

The film base is rather soft and is easily scratched unless handled carefully. Fingerprints are particularly difficult to remove and, therefore, should be avoided by using a soft wiping tissue as a protection when handling. Dust can be removed safely by use of a lens brush or a loosely crumpled soft paper tissue. When required, the filter can be cleaned with alcohol.

The effect of the filter will be evident mainly in the ground clutter area. Use of the filter will not require a change in camera aperture but some slight adjustment of radarscope controls, particularly video gain, may be necessary. The standard radarscope adjustment procedure should be carried out with the filter in place.

NOTE: Do not write on the McGill Filter.

To acquire McGill Filters, the order should be placed by memo through Regional Headquarters, to Chief, Radar Meteorology Staff, Weather Service Headquarters (W143x1).

0-15 Camera Internal Data

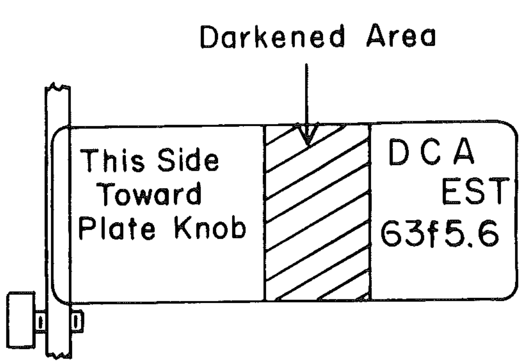


Figure 4. Data plate of 0-15 camera

The left one-quarter inch of the 0-15 data plate should be obscured with black tape or black grease pencil to permit visibility of the attenuation indicators that are superimposed on the film format. A small label may be substituted for the f-stop when the aperature is changing during the observations. A small gummed label with the station identification letters, year, and time zone typed in capital letters may be kept applied to the top right of the data plate. See figure 4.

If a hurricane is being photographed, the name of the hurricane should be entered on the data plate.

Setting Time on Accutron Clock. In this model Accutron, provision has been made to stop the second hand when the setting handle is lifted. Accutron, unlike conventional watches, has a unique free floating gear train. For this reason, the following procedure is required to set the hands exactly to the seconds:

(1) Lift the setting handle when the second hand is exactly at 60-second marker.

(2) Turn until the minute hand is directly over the correct minute marker. At this point the second hand may have advanced several seconds. Proceed as if the hand had not moved.

(3) When the second hand of the time standard reaches the 60th second, snap the setting handle back to its normal position. After a pause, the second hand will start. It will now be synchronized with the time standard.

CAUTION: Retention of the setting handle in the upright position will discharge the Power Cell at an excessive rate.

Setting the Day Counter on the Accutron Clock. Beginning at approximately 1700, the indexing mechanism of the day counter is gradually energized. The actual indexing occurs between 2400 and 5 min after 2400, at which point the counter is instantaneously advanced one count.

The counter can also be advanced by rotating the hands completely around in the clockwise direction, or by reversing the hands to 1700 and then advancing them until the number is indexed.

A special key is provided to set the individual numbers. Insert the point of the key in the appropriate hole in the side of the case and push until the number is indexed. Repeat indexing until the proper number is reached.

Battery Replacement. When the clock shows irregularities or stoppage, and near year end, replace the clock battery with a Bulova Accutron part No. 214-162 obtained from Weather Service stock (R650-BT501) or from a local jeweler. Do not substitute batteries and risk damaging this expensive clock. Use a dime to remove the cap screw, observe the old battery position, replace battery, and carefully thread the cap screw back and tighten.

Emergency Procedure. If the station camera is inoperative, drawings or sketches should be made of unusual echoes, especially those of precipitation area associated with hurricanes and tornadoes. When a hurricane is within the area of surveillance of a WSR-57 radar, a Polaroid photograph will be made once an hour to insure minimal photographing coverage in case the 0-15 camera is not operating properly.

As a precaution against a jammed camera or running out of film at a critical time, especially during severe weather situations, it is desirable that an extra loaded film magazine be on hand.

Replacement and Disposition of Defective Equipment. The Electronics Technician should be notified whenever any component of the radarscope photography system becomes inoperative and requires replacement. It is intended that each station will have one spare magazine and that overhauled and tested cameras and magazines will be available in the Central Logistic Supply Center.

PRE-OPERATING TEST PROCEDURE.

0-15 Pulse Camera System.

(1) Inspect the lens for dust or smudges. Brush or wipe gently.

(2) Inspect hood assembly for:

(a) hood forward in place on bezel

(b) camera shutter closed, f-stop set and noted on data card, clock running and correct

(c) camera mounted securely and cable connected

(d) film in magazine and no torn spracket holes. Note footage indicator.

(e) magazine seated properly and fastened firmly to camera

(3) To set PPI program on the control panel as follows: (figure 1)

1 EVERY 2 position, PPI position, and 0-15 power switch ON

(4) Inspect for:

(a) data chamber lamps on and correct intensity (R101 setting)

(b) hood lamps on and correct intensity (R303 setting). (Check all lamps by pressing test switch S501 on base of hood.)

(c) video and azimuth ring lighting correct intensity

(d) camera programs - shutter opens every other sweep and EXPOSING lamp glows

(e) film telltale indicators move with film advance

(f) FILM ALARM operates and resets (magazine off for 4 EXPOSURES then on)

(5) To end program, turn 0-15 POWER OFF.

(6) For TIME program, repeat (1) through (4) above then set control panel as follows: sequence switch-any position, TIMING at 5 to 60 min, program switch on TIME position, S105 ON, and 0-15 power switch ON.

(a) Pulse Delay alarms for 2 seconds and EXPOSING is delayed for about 30 seconds.

(7) For continued FILM ALARM, inspect footage indicator. If less than 30 ft is indicated on feed spool; remove the magazine and unload the film. When more than 30 ft is indicated, notify the technician. In severe weather conditions, substitute another loaded magazine.

Polaroid Camera System.

(1) Inspect lens for dust or smudges - brush or wipe gently.

(2) Inspect hood assembly for:

(a) hood forward in place on bezel

(b) camera shutter on "B" (bulb) and lens cap off

(c) film in camera and type noted

(d) camera mounted securely and cable connected

(3) Set control panel for program as follows: (figure 2)

Timer to 2 to 60 min, BUZZER switch ON, multiplier switch IX, EXPOSURES switch at 3 to 10, and POLAROID POWER ON.

(4) Inspect for:

(a) data chamber lamps on and correct intensity (R101 setting)

(b) hood lamps on and correct intensity (R303 setting). (Check all lamps by pressing test switch S501 on base of hood.)

(c) video and azimuth ring lighting correct intensity

(d) TIMING light shows and time decreases

(e) Pulse Delay alarms for 3 seconds and EXPOSING is delayed for about 30 seconds

(f) camera programs - shutter opens and EXPOSING lamp glows

(g) COMPLETE lamp and buzzer actuate at end of program.

(5) Turn POWER OFF and pull film through per instructions on film. To reset program, turn POWER ON.

(6) Pulse Delay is normally used. When the Pulse Delay is not desired, open the control cabinet top door and place the POLAROID power switch in the OFF position.

Defective Photographic Equipment. Notations will be made in the "Remarks" column of Form MF7-60 of the beginning and end of periods when the camera or its component equipment was inoperative.

If the 0-15 time-lapse camera, magazine, or control fails; take the following steps:

NOTE: Time-lapse camera units are not to be repaired locally.

(1) Request the Central Logistic Supply Center to send you the necessary replacement camera or magazine.

(2) Attach an "Instrument Return Tag" to each defective unit. The appropriate information should be entered in its correct place on the Instrument Return Tag. A brief explanation of the malfunction should also be entered on the tag.

(3) Wrap the defective unit in paper and pack it carefully. Do not use excelsior or material that has small particles or dust in it. Shredded or crumpled paper can be used as packing material. Defective unit(s) should be shipped via Parcel Post to the authorized repair location.

There will be no transfer of property accountability on 0-15 radar cameras or component units except for the internal clock, which is the only nonexpendable part. Nevertheless, all cameras and components are essential items and should not be cannibalized or disposed of in any manner without prior approval of the NWS Headquarters.

Since the photo-timer control unit for the 0-15 camera is a large and complex component, it is expected that the station electronics technician will maintain and repair this equipment.

If the Polaroid camera fails, the camera should be repaired locally by the station electronics technician or by a local camera repair firm. If this is not feasible, a wire or RAWARC message should be sent to the RH requesting a replacement unit.

16 MM CAMERA.

Loading Magazine. Insert the magazine through the rear door of the camera with the unexposed footage indicator facing the plate to which the hinged door is attached. The magazine should be inserted with a firm pressure, making certain that it is fully inserted before closing the door.

Setting the f-stop of Lens. To set the f-stop of the lens the following procedure should be used. Unscrew the two captive thumb screws on the camera mounting plate of the hood assembly. Rotate the hinged camera mounting plate 180° to the right. The lens is now accessible and the desired f-stop may now be set. The f-stop should be set to f-5.6 for average setting of the CRT intensity and Azimuth ring.

CAUTION: Do not let the camera mounting plate fall to open or closed position.

The lens has been focused and mechanically locked at the factory so the focus ring must not be moved. The lens may be unscrewed from its mount for cleaning.

DATA CHAMBER.

Removing Data Chamber Cover and Data Slate. To remove the data chamber cover unscrew the two captive thumb screws and lift the cover in a direction normal to the camera mounting plate. The Data Slate is removed by pulling the slate straight out of the guides to record or change the data. The Data Slate is inserted with the end opposite the word "DATA" first.

CAUTION: Inserting the data plate upside down will obstruct the 66 dB light. Commercially available gummed labels should be typed with the appropriate information and placed on the data plate.

Setting the Time and Date on the Accutron Clock. To set the Clock exactly to the second, lift up the setting handle when the second hand is exactly at 60 second marker. Turn until the hour hand is at the selected position and the minute hand is directly over the desired minute marker. At this point the second hand may have advanced several seconds. Proceed as if the hand had not moved. When the second hand of the time standard reaches the 60th second, return the setting handle to the flat position. After a pause the second hand will start. It will now be synchronized with the time standard.

CAUTION: Retention of the setting handle in the raised position will discharge the power cell at an excessive rate.

To set the date on the Clock insert the reset tool provided in the spare parts kit into the drum reset holes on the side of the Clock. By firmly pushing the reset tool the drum is advanced one digit.

Setting the time and date on the Clock is easily done with the camera mounting plate rotated to the open position.

Resetting the Frame Counter to Zero. The Frame Counter is reset by pushing the button that is located to the left of the row digits. The Frame Counter is made accessible by either removing the Data Chamber Cover or rotating the camera mounting plate to the open position.

Testing the Data Chamber Function Lamps. To test the 18 Data Chamber Function Lamps rotate the camera mounting plate to the open position and activate the toggle switch located on the top plate of the hood. All lamps must light.

Testing the Data Chamber Illumination Lamps. To test the three Data Chamber Illumination Lamps located in the hood, rotate the camera mounting plate to the open position. Turn the camera controller ON, selecting the alternate mode of operation. When the radar sweep reaches 360°, the three illumination lamps turn ON and remain ON for approximately 1 second.

Camera Controller. To operate the Controller the following procedure should be used: Set the Pre-determined Counter to the desired number of frames to be taken, usually 1,950 for a full magazine, by holding the reset button in the depressed position while simultaneously advancing the number wheels by means of the buttons above the wheels. The cover over the buttons opens to the left. When the Pre-determined Counter has counted down to zero the system automatically stops. Depress the POWER Switch, the desired Mode Switch, and the START Switch. The mode of operation may be changed at any time. To insure proper timing to the first frame after changing the mode, depress the Stop and Start buttons, respectively. It is not necessary to restart the system when switching to the alternate mode.

If the radar sweep is stopped while the controller is in the 5-, 10-, or 15-minute timing mode when the camera is supposed to take a picture, the system must be restarted by pushing the Stop and Start buttons respectively. If this procedure is not followed it may take 20 minutes for the timing circuit to reset itself and resume proper operation.

In the 5-, 10-, and 15-minute timing modes the Sonalert will sound a minimum of 30 seconds before the frame is exposed, allowing time for the radar operator to restart the radar sweep.

If the Stop Switch is pushed during exposure of a frame, the camera shutter will close with the next radar switch closure in order to preserve the last frame taken.

RHI Polaroid Hood. This camera accepts No. 47 Polaroid roll film. The camera back is opened by means of a lever located below the film cutter on the end of the camera. Directions for loading the film are printed on each roll of film. The dark slide below the Polaroid camera must be removed before pictures can be taken.

Polaroid Lens Markings. The markings on the speed dial of the lens represent the fractional parts of a second. The "T" or time setting allows the shutter to remain open after the lever has been pulled in the direction of the threaded boss and released. When the lever is again tripped in the same direction the shutter will close. The "B" or bulb setting allows the shutter to remain open as long as the lever is held in the "tripped" position. The shutter speed indicator is turned by means of the outside knurled disc. The "f" number should be set to f/11 for average setting of CRT intensity and range ring.

CAUTION: Do not attempt to lubricate the shutter mechanism in any manner.

Mounting and Removing the Polaroid Hood. The Polaroid Hood is installed on the RHI bezel by placing the slotted hood hinges over the hinge pins, pushing the hood towards the bezel, and pulling down until the hood is locked securely in place.

To remove the Polaroid Hood, push the hood up parallel to the bezel and pull the hood straight away from the bezel. To install the Polaroid Hood on the repeater scope rotate the 16-mm hood off the bezel and install the Polaroid Hood on the repeater scope as it was installed on the RHI bezel. The Polaroid Hood is removed from the repeater scope as it was removed from the RHI bezel.

System Start Up Procedure. With the radar on and the radar antenna rotating the following procedure should be used to start the 16-mm camera system:

a. Load magazine in camera.

b. Set f-stop of lens.

c. Enter data on data slate.

d. Set time and date on Accutron Clock.

e. Set Frame Counter to zero.

f. Test the Data Chamber Function Lamps.

g. Test the Data Chamber Illumination Lamps.

h. Set the Predetermined Counter.

i. Turn power on.

j. Press the desired Mode Switch.

k. Press the Start Switch.

Replacing Accutron Battery.

a. Unscrew the two captive panel screws on the data chamber cover and pull the cover straight away from the camera mounting plate.

b. Remove the cap screw from the rear of the clock.

c. Insert new battery, engaraved side facing movement, replace cap screw and tighten. If necessary, reset time and date.

FILE WITH SECTION V, RADARSCOPE PHOTOGRAPHY

POLICY AND PROCEDURE TO PROCURE COPIES OF RADARSCOPE FILM

The purpose of this issue is to outline the policy and procedure to be used in procuring copies of radarscope film.

The original copies of all radarscope film will be archived at the National Climatic Center in Asheville, North Carolina. When requested, NCC will provide copies to Weather Service Offices. It is not intended that each radar station maintain a library of the film, but rather that requests will be limited to reels needed for special purposes. Film should not be requested for use by persons outside the NWS, even if they are to use viewers or projection equipment in a Weather Service Office.

Copies of 35-mm radarscope film can be supplied in either registered or unregistered film. Unregistered film is suitable for use with hand-operated viewers but if used in a movie projector the frames will not stay properly aligned. Registered film is suitable for either hand-operated viewers or movie equipment, but copies are much more expensive. Consequently, requests for registered film should be made only when unregistered film cannot be used. Copies of 16-mm radarscope film are all registered.

Requests for radarscope film copies should include the station name, reel number, size needed, and whether the copy should be registered or unregistered. Requests should be addressed to:

National Climatic Center
Federal Building
Asheville, N.C. 28801

Attention: Climatic Information Section
(Radarscope Film)

FILE WITH SECTION V, RADARSCOPE PHOTOGRAPHY

PHOTOGRAPHY AT ARTCC SITES

Preparations.

READ CAMERA INSTRUCTIONS THOROUGHLY.

1. Obtain:

   a. Camera.

   b. Hood.

   c. Black cloth.

2. Be sure:

   a. Camera is loaded.

   b. Yellow marks on top of camera lens are on "outdoors or flash" on "3000 speed only" side.

   c. Electric eye has tape over it.

   d. Focus is on extreme closeup position.

   e. Film speed is on 3000.

   f. White film tab shows on right side of camera.

   g. Camera is cocked - No. 3 lever is down.

   h. Overhead lights are out.

3. Attach camera to hood or tripod.

4. Attach cable release to camera.

5. Attach hood to radar scope.

a. Be sure:

1. It is straight.

2. Clip (on hood) is behind top lip of scope panel.

3. Press interlock button on left side near handle to scope panel before pulling out.

6. Set camera lens even with rim of hood.

a. Be sure:

1. Camera points straight in toward face of scope.

Radar Settings.

1. Range marks 20 miles at maximum intensity for 200-mile range; range marks 10 miles for 100-mile range.

2. Cursor set on true north for that particular radar system and full off.

3. Set IF gain for slight grass return at the outer edge of the scope.

4. STC off for 5 sweeps if possible.

5. Background normal slightly on to eliminate inverted video.

6. Beacon indicator off.

7. Compass lights full off.

Operation.

1. Place black cloth over camera and your head to eliminate light leakage and reflections.

2. Press cable release and hold down for complete sweep.

3. Turn Cursor intensity full ON for 10 seconds.

4. Turn compass rose intensity full ON for 10 seconds (No. 3 and No. 4 should be done during exposure).

5. Release cable release button.

6. Pull white film tab (yellow tab should appear) clear out of camera.

7. Pull yellow film tab (will come clear out with picture).

8. Time for 15 seconds after pulling yellow tab out.

9. Peel film from backing.

10. Coat picture with wax applicator (came with film pack).

11. Let dry for 20 minutes.

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SECTION VI
LOCAL INSTRUCTIONS

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