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EVALUATION OF A REMOTE WEATHER RADAR DISPLAY

Vol. II - Computer Applications for Storm Tracking and Warning

W. David Zittel

Final Report

December 1976

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16. Abstract

Tests with a Remote Radar Display using R,θ coordinates had demonstrated the feasibility of presenting timely warnings for areas in severe storm paths graphically. Mathematical derivations and three case studies utilizing operationally oriented software are presented with suggestions for future work.

This research is divided in two parts. Volume I describes the installation of equipment, training of FSS briefers in operation and interpretation, and documentation of data transmitted during the tests. Volume II summarizes research efforts at NSSL to computerize further processing of the displayed data for rapid isolation and tracking of selected storms.

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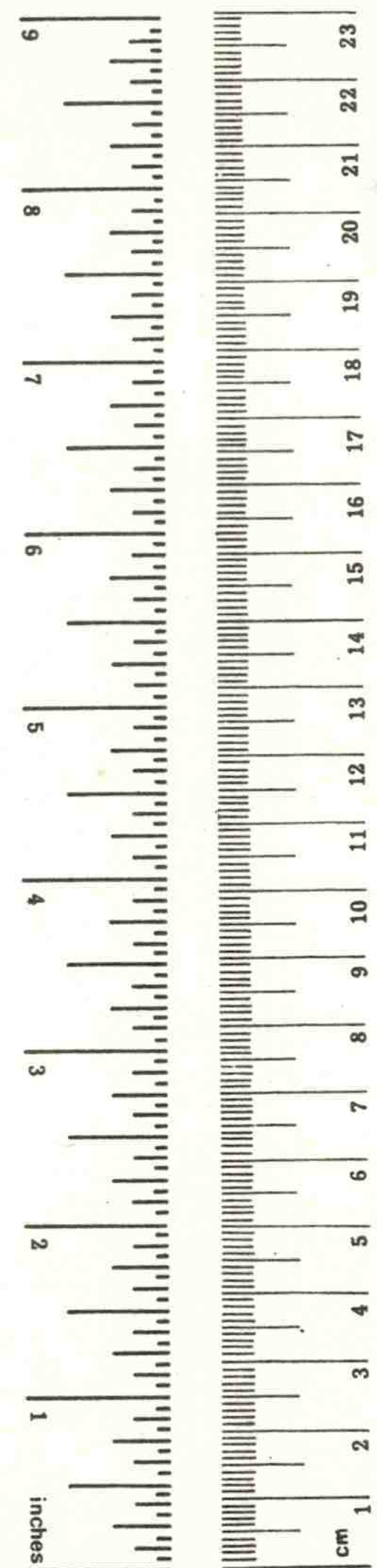
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

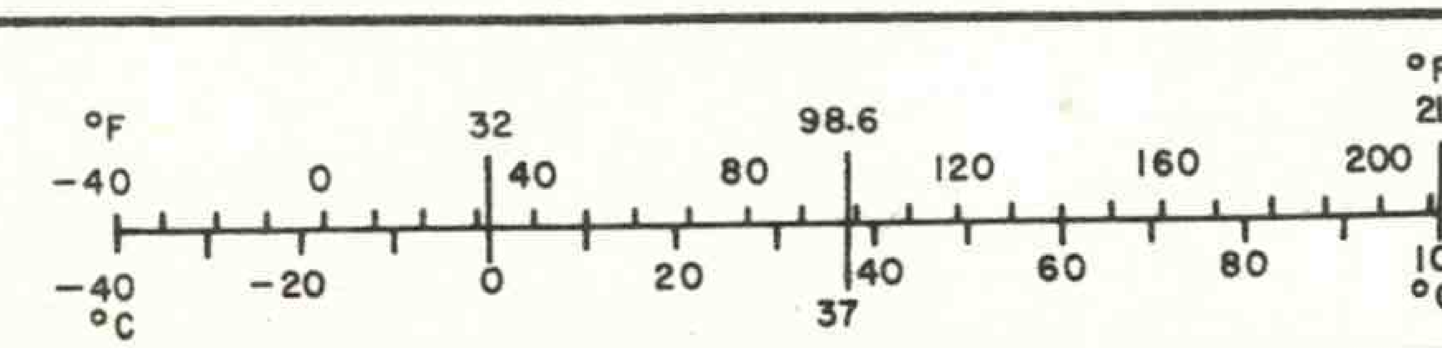
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

The Federal Aviation Administration and the National Severe Storms Laboratory are cooperating in search of improved methods for severe storm prediction and warning for aviation. Here NSSL Operations staff reports on tests involving transmission of contour-mapped WSR-57 weather radar from NSSL headquarters to a display unit at the Oklahoma City Flight Service Station.

Our study follows other investigations of the comparative value of various radar systems for severe storm surveillance. Improved signal processing and communication techniques and equipment now permit rapid dissemination of information concerning storm location, intensity, and movement and offer a new dimension in weather display for general aviation.

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a	Fourier coefficient subscript denoting arrival time
a_n	Fourier coefficient of nth harmonic
A	coefficient of general equation of ellipse
A'	coefficient of raotated ellipse
A_x	coefficient of linear least squares equation for X(t)
A_y	coefficient of linear least squares equation for Y(t)
b	Fourier coefficient subscript denoting beginning point time
b_n	Fourier coefficient of nth harmonic
B	coefficient of general equation of ellipse
B_x	coefficient of linear least squares equation for X(t)
B_y	coefficient of linear least squares equation for Y(t)
c	Fourier coefficient
c_n	Fourier coefficient of nth harmonic
C	coefficient of general equation of ellipse
C'	coefficient of rotated ellipse
d	Fourier coefficient subscript denoting distance
d_n	Fourier coefficient of nth harmonic
e	base of natural logarithms subscript denoting ending point, time
G	gatelength
i	index counter

k	time constant in weighting function
K	constant of general second order equation for ellipse
ℓ	subscript denoting last point, time
L	perimeter of echo for arc length function
M	total number of discrete line segments to describe echo perimeter slope of straight line
n	denotes number of harmonic number of centroid entries for echo tracking
N	number of points used in LLS equation
$p_i q_i$	coefficients of linear line for discrete arc lengths
P_b	beginning points along the echo path for warning area
P_e	ending point along echo path for warning area
P_o	last centroid position entered
R	range between two points
$R_1 R_2$	distance to two consecutive gates
s	arc length parameter
s_i	discrete arc length
t	time
t_b	beginning time
t_e	ending time
t_i	time of ith centroid entry
t_ℓ	time of last centroid entry
t_n	same as t_ℓ
W	weighting parameter

LIST OF SYMBOLS (cont.)

x	subscript for coefficients of linear least squares equation
X	independent variable
X_ℓ	last position of X(t)
X(s)	parametric function of arc length for X
X(t)	parametric function of linear least squares equation for X
$(X,Y),(X',Y')$	denotes points in Cartesian coordinates
XM	slope of echo track
y	subscript for coefficients of linear least squares equation
Y	dependent variable
Y_ℓ	last position of Y(t)
Y(s)	parametric function of arc length for Y
Y(t)	parametric function of linear least squares equation for Y
$\Delta\alpha$	angular change
Δt	change in time
ε_d	distance error in echo tracking
ε_t	time error in echo tracking
Θ	angular difference between consecutive radials
σ_d	RMS estimates of distance error
σ_t	RMS estimates of time error
ω	smallest angle to rotate approximating ellipse to eliminate cross product terms

EVALUATION OF A REMOTE WEATHER RADAR DISPLAY

VOLUME II

Computer Applications and Techniques for Storm Tracking and Warning

W. David Zittel

1. INTRODUCTION

This report extends tests of the remote radar display described in Volume 1 and examines the feasibility of the display as a graphics terminal. A storm tracking program has been combined with an echo contouring scheme to produce graphic warning areas based on size and motion of storm echo areas.

A detailed description is provided of the mathematical techniques employed and a quasi-real time software program is outlined. In addition, three case studies utilizing the above logic are presented. Finally, a summary of results and suggestions for improvements and future work are discussed.

2. BACKGROUND

Information regarding storm motion and growth tendencies are now presented to the FSS pilot-briefer in two forms. First, a numerical coding in the hourly radar report transmitted by teletype (RAREP) indicates the past tendency of storm pattern growth or decay. Motion, in polar coordinates, of both the pattern and individual cells are included.

Secondly, a plain language summary provides a "layman's" geometric description of the storms with geographical references to outline the present and projected coverage. Severe Storm Warnings and special advisories to airmen (SIGMETS and AIRMETS) carry information on hazardous flight conditions. At a few locations, these messages are augmented by a facsimile machine replica of the Plan-Position Indicator (PPI) with appropriate annotations (Bigler, 1969).

The reliability of both types of advisories varies directly with the spatial and temporal variance of radar echo patterns. Information contained in the RAREP is usually a sterile summary of the radar scope display, condensing details observed and coded during a specific 15 minute period. Plain language summaries and advisories may include information on the position and movement of fronts and squall lines, and observations of recent severe weather events.

During periods when echo coverage and/or intensity change rapidly special observations supplement hourly reports. During periods of severe weather, the National Weather Service radar scopes are monitored constantly, but because the flow of information is restricted by communication facilities and the heavy work load required to meet various local, state and national needs, messages to the FSS are periodic.

The Volume I tests have shown that if calibrated contoured data are available routinely at the FSS, pilot briefers can interpolate between National Weather Service advisories and maintain a "user's watch" of storm locations and intensities. However, neither time nor expertise is available at the FSS to relate echo patterns to synoptic scale disturbances (wind, pressure, and moisture fields) and severe weather reports. Even with such data, it is difficult for meteorologists to predict changes in gross features of precipitation areas.

Fortunately, large severe storms tend to be steady-state and lend themselves to tracking and extrapolation. The principal objective of this study is to apply semi-automated computerized logic to identify, track, and extrapolate those storms of sufficient intensity and size to produce hazardous weather conditions and to map out a warning area for the extrapolated storm positions.

3. RATIONALE FOR SELECTING AND TRACKING ECHO CENTROID (OR WHY LEAVE A PERSON IN THE PICTURE)

Several years experience in field operations at NSSL have stressed the value of retaining the meteorologist for real time decision making. It seems difficult, if not impossible, to anticipate all the complicated elements occasionally present in real weather situations, in a computer program.

Several objective techniques have been suggested by Kessler and Russo (1963), Wilson (1966), and Blackmer and Duda (1972), which rely on spatially correlating PPI information to derive echo motion and speed. As shown in Figure 1, significant storms on the radar scope may have quite different motions. Also under certain conditions severe storms split with one portion often moving to the left of the average ambient wind direction and faster than the wind speed, while the other portion moves to the right and slower than the ambient wind (Newton and Fankhauser, 1964). Under these conditions a single speed and direction of motion for the whole scope would be misleading.

Even if individual echoes are first isolated (Wilk, 1966), there are several drawbacks to using this approach. In a matrix analysis, a minimum of two PPI's must be stored at the same time requiring a large computer core. Generally, the two fields should have uniform grid density which an R, θ system doesn't have. In an R, θ system, data must be scan-converted to rectilinear coordinates before correlating the data. Both scan conversion and correlation techniques are time consuming. Care also must be taken when scan converting to assure that spatial averaging has not changed the distribution of intensity integers.

By contrast, the echo centroid extrapolation technique requires only a small amount of core and is very fast. One can operate the program with radar data extracted manually from the PPI scope display. One may also, in a relatively short period of time, use limited automation to scan a PPI for centroid information, and display it regularly without full time monitoring. (Such a technique is presented in section 5.) Tests during the NSSL Spring Program (Wilk and Gray, 1970) indicate an operator can easily filter extraneous or unwanted data. Some storms may be moving beyond the radar scope's range while others may be part of a broad band of non-severe stratiform rain whose overall movement is slower and more persistent (fig. 2).

An operator may recognize splitting or merging storms which need to be treated as new echoes. (Computer programs to date have not proved reliable in echo matching and we make no attempt to do this here.)

One final reason for leaving an operator in the picture is to insure detection of system failures and to recognize spurious, non-meteorological results when computerized objective analysis software systems are in operation. The following sections are devoted to the operation of a man-machine mix using examples of real data sets.

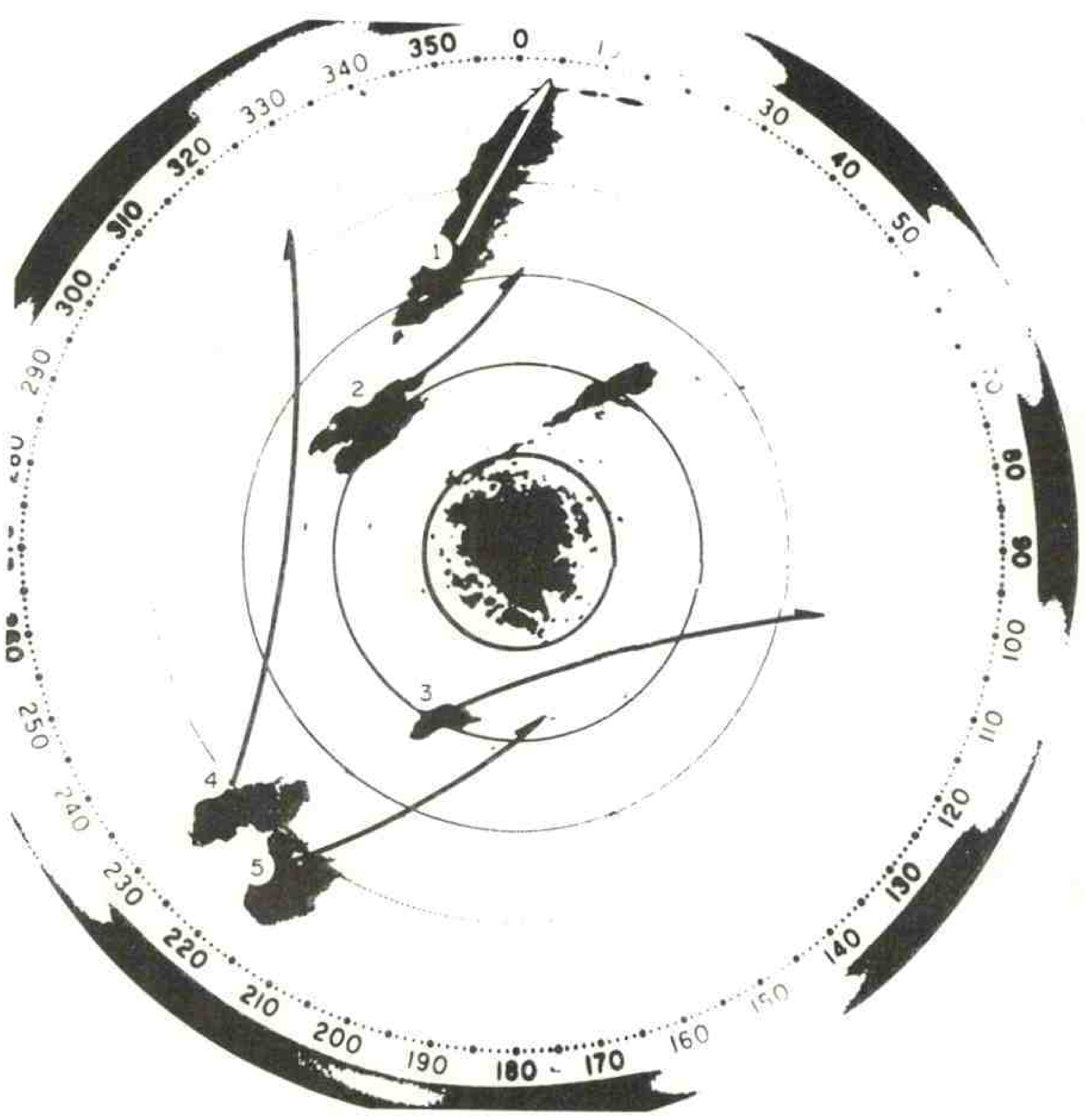

Figure 1. WSR-57 radar PPI, 100 n mi. range, 20 n mi. range marks, 1454 CST, April 3, 1964. Individual echoes are numbered one to five.

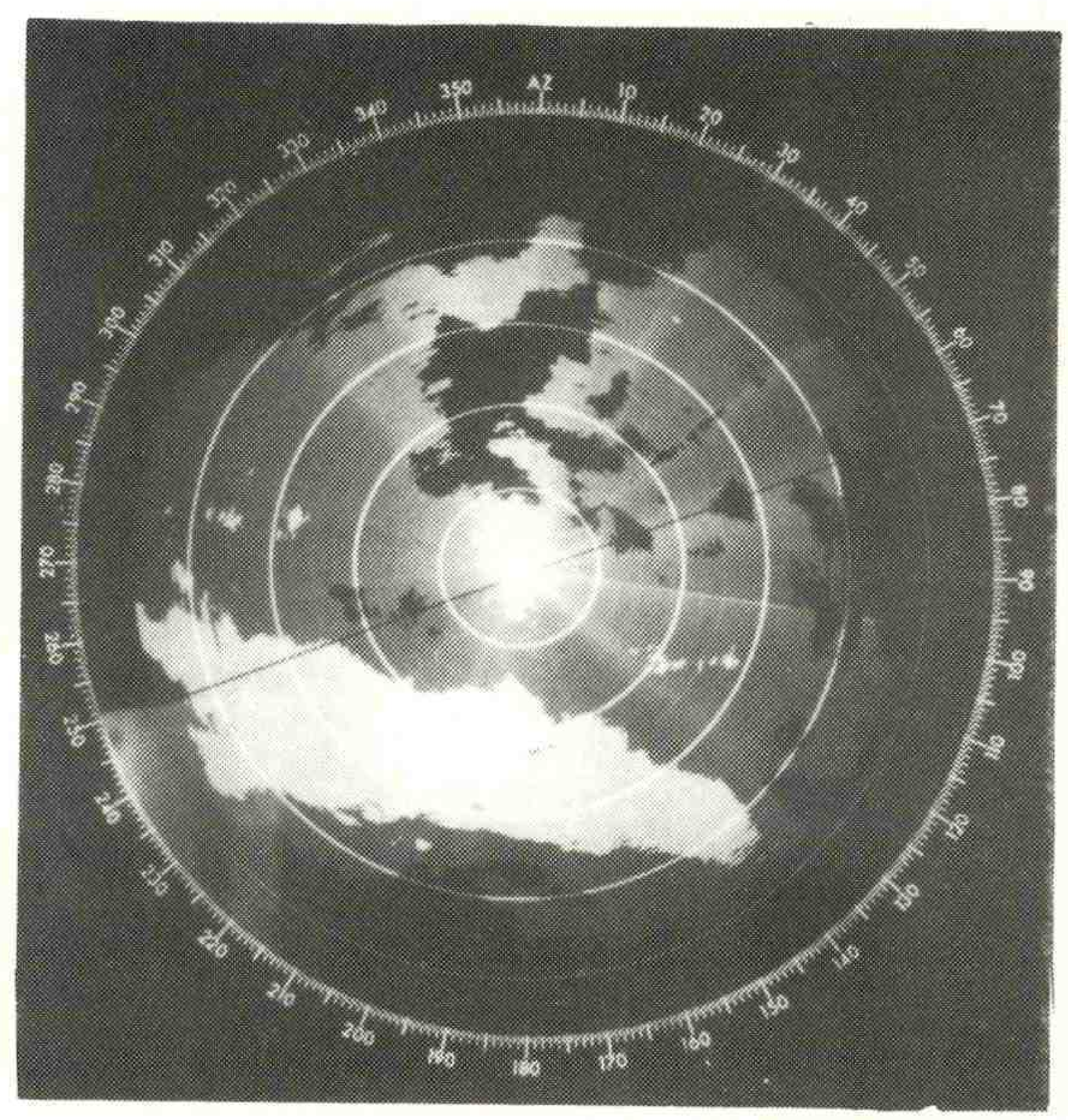

Figure 2. WSR-57 radar PPI, 200 km range, 40 km range marks, 1132 CST, September 24, 1974. Light to moderate stratiform showers indicated over most of the radar scope.

4. MATHEMATICAL FORMULATION

4.1 Introduction

Three sources of information are used to construct a graphic presentation of a warning area. In order of calculation, they are (a) echo centroid and shape, (b) echo motion, and (c) a measure of the variance of the echo motion. The method used to calculate echo centroid and shape basically requires fitting an arc length function to the echo's perimeter and was suggested by Blackmer and Duda (1972), later developed by Östlund (1974). Calculation of echo motion and variance using centroid positions was developed by Barclay and Wilk (1970) and run operationally during the 1970 Spring Data Collection Program.

4.2 Echo Shape and Centroid Calculation

Use of the arc-length function to describe echo shape requires that one first determine echo perimeter. In the computer logic developed for this report, data are entered into core and all bins with intensity less than a specified level are first set to zero. Then, beginning with zero degrees azimuth, the PPI is searched until an echo is found. Then the program isolates the echo, moving around the perimeter in a counterclockwise direction until it comes upon the starting point. This logic differs from Östlund's in at least two respects. First, the echo's perimeter is defined in an R,θ coordinate system; and second, the program minimizes echo area. The following two examples in B scan format illustrate these points.

In Figure 3 the arrows indicate the path followed in the boundary search. S is the starting gate, X's represent echo, dots--no echo. Echo 1 is joined to echo 2 by a single gate along a common radial. The program ignores that gate since it would have to be used twice in order to close the boundary and combine echo 1 and 2. Likewise, between echo 2 and echo 3 there is a common corner. But because the corner gates would have to be used twice, the echoes are separated.

No gate is used twice except the starting one and no gate is accepted unless there is an acceptable gate beyond it. The subroutine BNDRY (called from CONTUR) contains this logic.

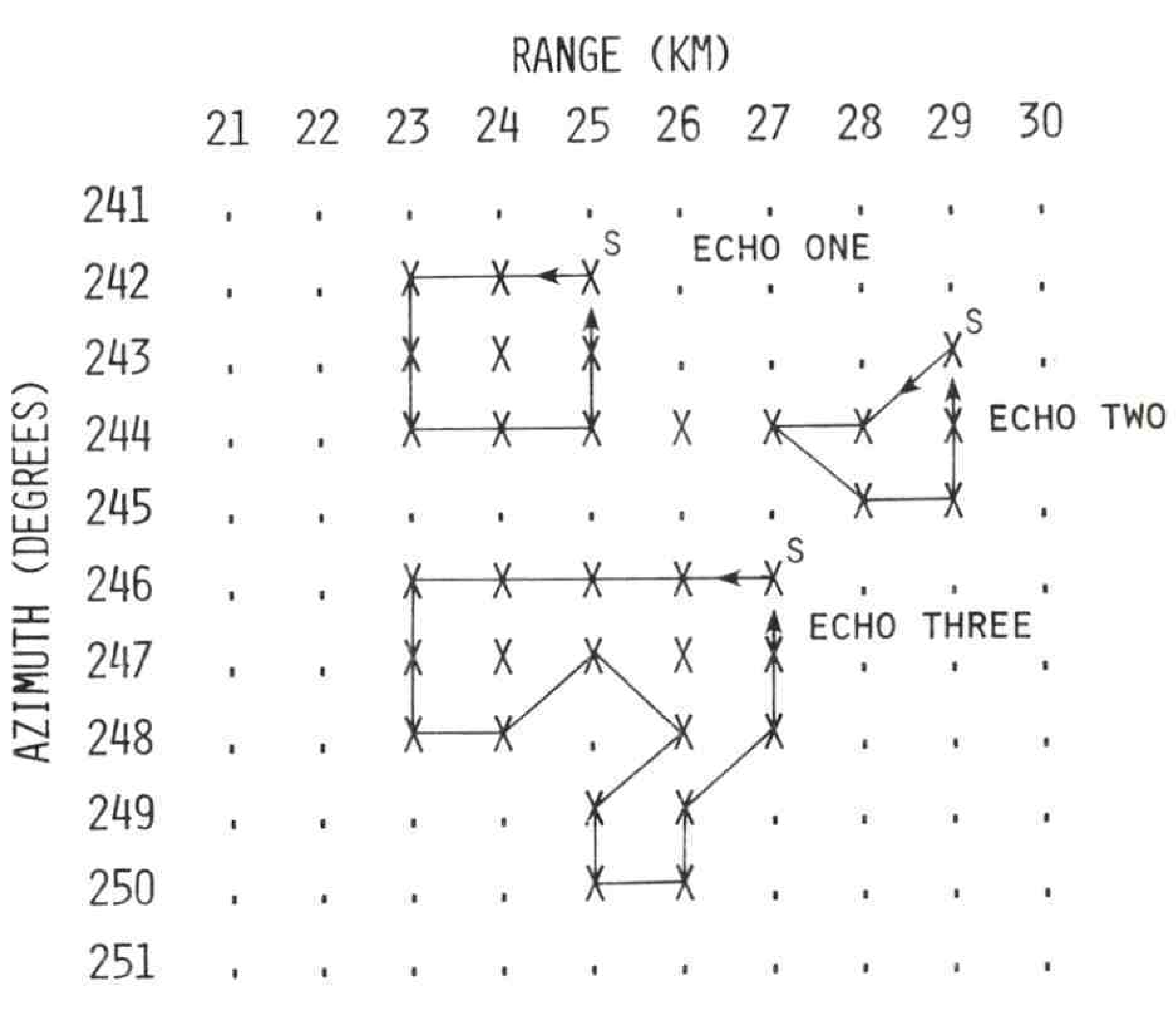

Figure 3. Representative echo samples show the path and order of points to describe echo perimeter.

The obvious result of the above, is that cores tend to be discrete with a more regular shape.

After a closed boundary is found, the area of echo is calculated by summing up all bins within and including the perimeter. The area of a bin is given by $(\theta\pi R_1^2 - \theta\pi R_2^2)/360°$, which can be factored into $\theta\pi(R_1 - R_2)(R_1 + R_2)/360°$. Since the difference between R_1 and R_2 is the gatelength of the radar, G, and θ is the angular difference between radials, the area of an individual bin is

$$\frac{\theta\pi G(2R_1 - G)}{360°} \quad . \tag{1}$$

If an echo's area is less than a specified threshold, it is ignored and the program searches for a new echo. If an echo exceeds the specified area, Fourier analysis of its shape is performed. If the area is more than five times the specified area, the lowest intensity is purged and the remaining core treated as a new echo. This process is iterated until the echo is less than the specified area.

Once an echo meets the size criterion, the program enters subroutine OSTLND. Here the paired azimuth and range perimeter data are converted to Cartesian points. Fourier analysis of X(s) and Y(s) is performed where s is the arc length function. Mathematically these functions are:

$$X(s) = \sum_{n=0}^{\infty} a_n \cos\left(\frac{2n\pi s}{L}\right) + b_n \sin\left(\frac{2n\pi s}{L}\right) \tag{2}$$

$$Y(s) = \sum_{n=0}^{\infty} c_n \cos\left(\frac{2n\pi s}{L}\right) + d_n \sin\left(\frac{2n\pi s}{L}\right) \quad . \tag{3}$$

The coefficients a_n, b_n, c_n, and d_n may be expressed as

$$a_n = \frac{2}{L}\int_0^L X(s) \cos\left(\frac{2n\pi s}{L}\right) ds \tag{4}$$

$$b_n = \frac{2}{L}\int_0^L X(s) \sin\left(\frac{2n\pi s}{L}\right) ds \tag{5}$$

$$c_n = \frac{2}{L}\int_0^L Y(s) \cos\left(\frac{2n\pi s}{L}\right) ds \tag{6}$$

$$d_n = \frac{2}{L} \int_0^L Y(s) \sin\left(\frac{2n\pi s}{L}\right) ds \qquad (7)$$

where n, an integer, is the nth harmonic.

Each coefficient may be rewritten:

$$a_n = \frac{2}{L} \sum_{i=1}^{M} \int_{s_i}^{s_{i+1}} X(s) \cos\left(\frac{2n\pi s}{L}\right) ds \qquad (8)$$

where M is the number of discrete points in the echo's boundary. Also, since X(s) may be considered as consisting of a series of discrete line segments, one may set $X(s_i) = p_i + q_i s_i$. Setting this expression into Eq. (8) and integrating yields:

$$a_n = \frac{2}{L} \sum_{i=1}^{M} \left| \frac{p_i L}{2n\pi} \sin\left(\frac{2n\pi s_i}{L}\right) + \frac{q_i L^2}{(2n\pi)^2} \cos\left(\frac{2n\pi s_i}{L}\right) + \frac{s_i L}{2n\pi} \sin\left(\frac{2n\pi s_i}{L}\right) \right|_{s_i}^{s_{i+1}} \qquad (9)$$

Eq. (9) and the corresponding equation for each of the other coefficients are calculated in the computer. The 0th harmonic yields the mean of each series and thus the centroid of the echo's shape. Eight harmonics in addition to the mean are calculated.

Because the values are derived initially from a polar scan, the density of points about the perimeter is not constant, biasing the centroid location towards the radar. In a hypothetical case, using a circle of 10 km radius, the resulting centroid error varies as a function of range (fig. 4) and is a maximum at 10 km. However, for an echo with stable motion there is little error because all centroids have the same bias.

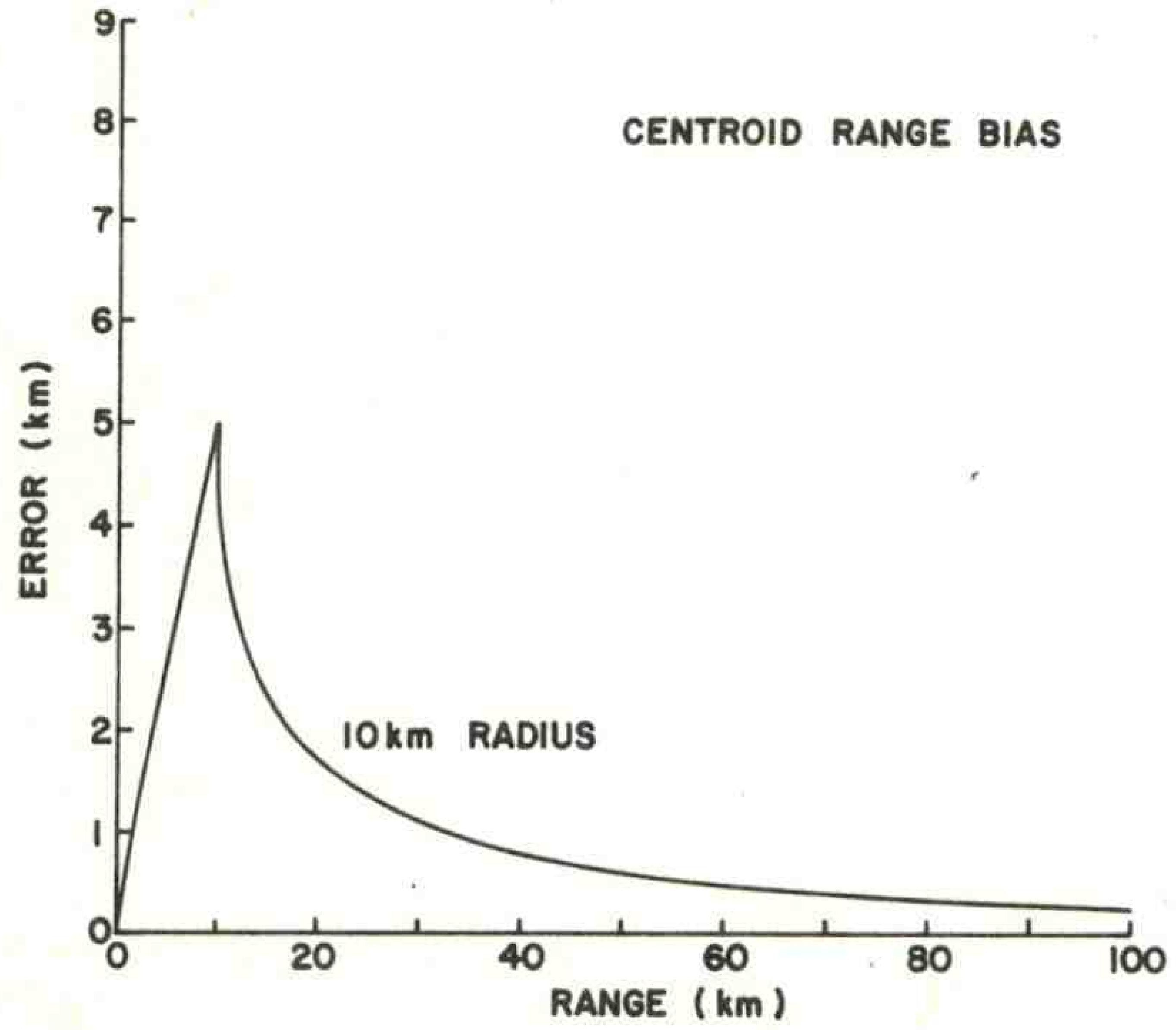

Figure 4. Graphic presentation of error in determining the echo centroid due to non-uniform perimeter density for a hypothetical circular echo with a 10 km radius.

4.3 Echo Motion Calculation

The calculation of echo motion uses linear least squares (LSS) equations fitted through an echo's past centroid positions expressed parametrically as a function of time as

$$X(t) = A_x t + B_x \tag{10}$$

$$Y(t) = A_y t + B_y \tag{11}$$

where A_x and A_y are found by solving

$$A_x = \frac{N\Sigma Xt - \Sigma X \Sigma t}{N\Sigma t^2 - (\Sigma t)^2} \tag{12}$$

$$A_y = \frac{N\Sigma Yt - \Sigma Y \Sigma t}{N\Sigma t^2 - (\Sigma t)^2} \quad . \tag{13}$$

The ordinate axis intercepts, usually found by solving

$$B_x = \overline{X} - A_x \overline{t} \tag{14}$$

and

$$B_y = \overline{Y} - A_y \overline{t} \quad , \tag{15}$$

are here given as

$$B_x = X_\ell - A_x t_\ell \tag{16}$$

and

$$B_y = Y_\ell - A_y t \tag{17}$$

where t_ℓ, X_ℓ and Y_ℓ are the echo's last position in time and space. This condition forces the LSS equations through the last point.

From Eqs. (10) and (11) echo speed is simply

$$SPD = (A_x{}^2 + A_y{}^2)^{1/2} \tag{18}$$

and the direction of motion is

$$DIR = TAN^{-1}(A_x/A_y) + 180 \quad . \tag{19}$$

A measure of an echo's predictability in time and distance is determined by comparing the time of the latest centroid position to the predicted time of closest passage to that centroid position. The difference, Δt, is defined as the error in time, ε_t. The distance between the predicted point of closest passage and the actual centroid location is defined as

$$\varepsilon_d = [(A_x t + B_x - X)^2 + (A_y t + B_y - Y)^2]^{1/2} \tag{20}$$

where t is the time of closest passage and X and Y are the Cartesian coordinates of the latest centroid position. We can solve for the unknown time, t, by first squaring terms in Eq. (20) and then differentiating them with respect to t yielding:

$$\frac{d(\varepsilon_d)^2}{dt} = 2A_x(A_x t + B_x - X) + 2A_y(A_y t + B_y - Y) . \tag{21}$$

Setting the expression on the right equal to zero and solving for t yields

$$t = \frac{A_x(X - B_x) + A_y(Y - B_y)}{A_x^2 + A_y^2} . \tag{22}$$

Therefore ε_t is $t - t_\ell$ where t_ℓ is the time of the latest centroid. Given t, ε_d can be calculated directly from Eq. (20).

Finally, ε_t and ε_d are normalized to one hour and root mean square errors (RMSE) computed from

$$\mathrm{RMSE}_d \equiv \sigma_d = \left[\frac{\sum_{i=1}^{n}\left(\frac{\varepsilon_d}{t_n - t_{n-1}}\right)^2}{n}\right]^{1/2} \tag{23}$$

and

$$\mathrm{RMSE}_t \equiv \sigma_t = \left[\frac{\sum_{i=1}^{n}\left(\frac{\varepsilon_t}{t_n - t_{n-1}}\right)^2}{n}\right]^{1/2} \tag{24}$$

for $n \geq 3$, where n is the number of points in a discrete track.

4.4 Warning Area Calculations

We can now combine the results of sections 4.2 and 4.3 to determine a warning area. Given a beginning time, t_b, and ending time, t_e, we first solve Eqs. (10) and (11) for the starting and ending points P_b and P_e, of the warning area specified in the time domain, which lie on the echo path (fig. 5). A measure of a storm's predictability in time is included in determining P_b and P_e as follows:

For P_b

$$X = A_x(t_b - \sigma_t) + B_x \tag{25}$$

$$Y = A_y(t_b - \sigma_t) + B_y \tag{26}$$

and for P_e

$$X = A_x(t_e + \sigma_t) + B_x \tag{27}$$

$$Y = A_y(t_e + \sigma_t) + B_y \; . \tag{28}$$

Next, two line segments are found which are parallel to and the same length as the major axis of the echo and which pass through P_b and P_e, respectively. The length and orientation of the line segments are determined by finding an ellipse which approximates the echo at hand.

A parametric form of an ellipse is given by the zeroth and first harmonics of the echo. For convenience the ellipse is translated to the origin eliminating the zeroth harmonic from further calculations. From Eqs. (2) and (3) Cartesian coordinates expressed as a function of the arc length, s, for any point on the ellipse are given by

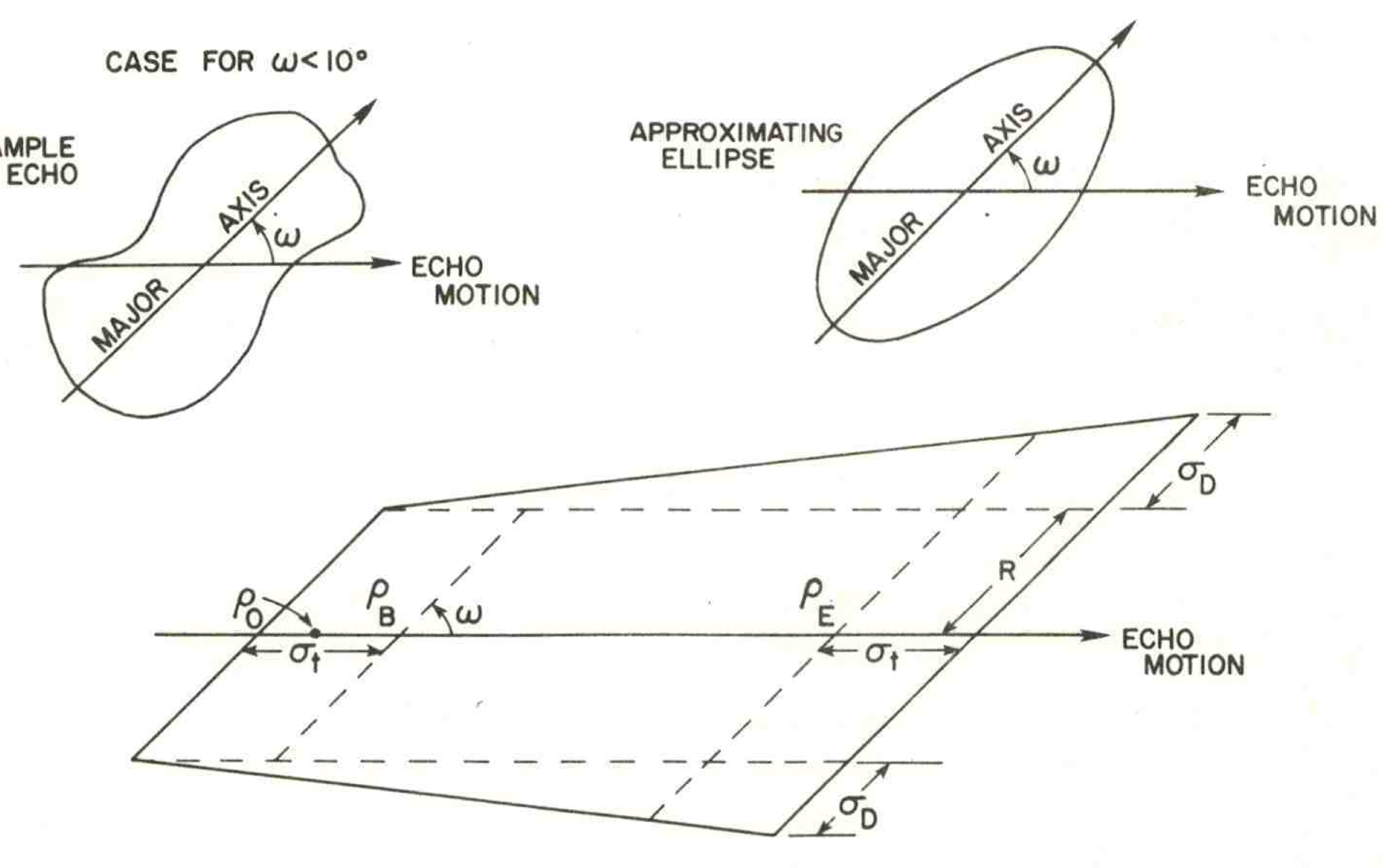

Figure 5. Illustration of use of an approximating ellipse, linear least squares predicted echo trajectory and the RMSE values to calculate graphic warning area for ω > 10 degrees.

$$X(s) = a_1 \cos(\frac{2\pi s}{L}) + b_1 \sin(\frac{2\pi s}{L}) \quad (29)$$

$$Y(s) = c_1 \cos(\frac{2\pi s}{L}) + d_1 \sin(\frac{2\pi s}{L}) \quad . \quad (30)$$

Also, an ellipse has the second degree form

$$AX^2 + BXY + CY^2 = K \quad (31)$$

where A, B, C and K are constants. By combining Eqs. (29) and (30) with Eq. (31) we can find three equations with which to solve for A, B and C from which the orientation of the ellipse is found. A value for K is specified below. Setting Eqs. (29) and (30) into (31) yields:

$$K = A(a_1 \cos(\frac{2\pi s}{L}) + b_1 \sin(\frac{2\pi s}{L}))^2 + C(c_1 \cos(\frac{2\pi s}{L}) + d_1 \sin(\frac{2\pi s}{L}))^2$$
$$+ B(a_1 \cos(\frac{2\pi s}{L}) + b_1 \sin(\frac{2\pi s}{L}))(c_1 \cos(\frac{2\pi s}{L}) + d_1 \sin(\frac{2\pi s}{L})) \quad . \quad (32)$$

Expanding and combining like terms gives us:

$$K = (Aa^2 + Bac + Cc^2) \cos^2(\frac{2\pi s}{L}) + (Ab^2 + Bbd + Cd^2) \sin^2(\frac{2\pi s}{L})$$
$$+ (2Aab + B(ad + bc) + 2Ccd) \sin(\frac{2\pi s}{L}) \cos(\frac{2\pi s}{L}) \quad . \quad (33)$$

When $2\pi s/L = 0$, $\sin(0°) = 0$ and $\cos(0°) = 1$; when $2\pi s/L = \pi/2$, $\cos(\pi/2) = 0$ and $\sin(\pi/2) = 1$.

Under these two conditions Eq. (33) reduces to the following two identities

$$K = Aa^2 + Bac + Cc^2 \quad (34)$$

$$K = Ab^2 + Bbd + Cd^2 \quad . \quad (35)$$

Since they contain only constants they are valid for all s and K can be set into Eq. (33) as:

$$K = K \cos^2(\frac{2\pi s}{L}) + K \sin^2(\frac{2\pi s}{L})$$
$$+ (2Aab + B(ad + bc) + 2cd) \sin(\frac{2\pi s}{L}) \cos(\frac{2\pi s}{L}). \quad (36)$$

From trigonometry $\sin^2\omega + \cos^2\omega = 1$ and similarly $K \sin^2\omega + K \cos^2\omega = K$. Hence, for Eq. (36) to be valid when $\sin(2\pi s/L)$ and $\cos(2\pi s/L)$ both $\neq 0$

$$2Aab + B(ad + bc + 2Ccd) = 0 \tag{37}$$

must be true. Since a, b, c, and d are simply the coefficients of the first harmonic, only A, B, C and K are unknown.

From Eq. (29) a maximized value of X(s) is $(a^2 + b^2)^{1/2}$ and from Eq. (30) a maximized value of Y(s) is $(c^2 + d^2)^{1/2}$. Therefore a maximum value for $(X(s)^2 + Y(s)^2)^{1/2}$ is $a^2 + b^2 + c^2 + d^2)^{1/2}$ which is set equal to K. This gives us a fairly accurate measure of the ellipse's semimajor axis. K, as computed above, will always be slightly greater than the true length of the semimajor axis. However, this is quite satisfactory since the length of the echo's axis is the sum of several harmonics and not just of the first harmonic alone.

Using determinants, A, B, and C may be found by solving Eqs. (34), (35) and (37) simultaneously. Specifically

$$A = \frac{\begin{vmatrix} K & ac & c^2 \\ K & bd & d^2 \\ 0 & \frac{1}{2}(ad + bc) & cd \end{vmatrix}}{\begin{vmatrix} a^2 & ac & c^2 \\ b^2 & bd & d^2 \\ ab & \frac{1}{2}(ad + bc) & cd \end{vmatrix}} . \tag{38}$$

Expanding the determinants and combining like terms yields:

$$A = \frac{K(bcd^2 + \frac{1}{2}(a^2 - d^2)(ad + bc) + adc^2)}{2(a^2bcd^2 - ab^2c^2d) + \frac{1}{2}(b^2c^2 - a^2d^2)(bc + ad)} . \tag{39}$$

B and C are computed likewise.

Once the ellipse's coefficients have been found, its orientation can be determined using the relationship (Morris and Brown, 1937)

$$\tan(2\omega) = \frac{B}{A-C} \tag{40}$$

or

$$\omega = \frac{1}{2}\tan^{-1}\left(\frac{B}{A-C}\right) \quad . \tag{41}$$

There is an ambiguity as to which axis of the ellipse from which ω is measured. This ambiguity may be resolved by considering the sign and relative size of A, B and C. However, if the ellipse is first rotated through angle ω eliminating B, its equation becomes

$$A'X^2 + C'Y^2 = K \quad . \tag{42}$$

Then if A' is less than C', ω is measured with respect to the major axis; if C' is greater than A', ω is measured with respect to the minor axis.

Now if the slope of a line, the length between two points on that line, and the coordinate of one of the points are all known, we may solve for the coordinates of the unknown point by combining the equation of a straight line with the equation for the distance between two points. Further assume that the given line intersects the echo path at (X',Y') where X' and Y' are known and the unknown coordinates are X and Y. Then

$$Y - Y' = M(X - X') \tag{43}$$

where $M = \tan\omega$ is the slope of the line and

$$R^2 = (Y - Y')^2 + (X - X')^2 \tag{44}$$

where R is the distance between (X,Y) and (X',Y'). We square Eq. (43) and set it into Eq. (44) yielding

$$R^2 = M^2(X - X')^2 + (X - X')^2 \quad . \tag{45}$$

Factoring and transferring terms yields

$$\frac{R^2}{M^2+1} = (X - X')^2 \quad . \tag{46}$$

Finally, taking the square root of each side and solving for X gives us

$$X = X' \pm (R^2/(M^2 + 1))^{1/2} \tag{47}$$

and Y for each X is given by

$$Y = Y' + M(X - X') \quad . \tag{48}$$

Thus, we have found two points--one above and one below the echo path which define the initial warning boundary. There are also two points which define the final warning boundary. These four points define the warning area. R in the above equations is equivalent to K in the general equation of the ellipse. However, in solving for the above points, R is modified to include σ_d. σ_d is scaled linearly such that the total length for R is given by

$$R = K + \sigma_d \; |t_b - t_\ell| \qquad \text{at } P_b \tag{49}$$

$$\text{and } R = K + \sigma_d \; |t_e - t_\ell| \qquad \text{at } P_e \quad . \tag{50}$$

t_ℓ is the time of the last echo observation.

From Figure 6 it will be recognized that the warning area is a modified parallelogram. However, as the echo's major axis becomes more closely aligned with the echo motion, the parallelogram closes. Therefore, whenever the echo's motion and the echo's major axis are within 10 degrees of each other, the minor axis of the best fit ellipse is used for K and the slope of the lines passing through P_b and P_e, respectively, are given as -1/XM where XM is the slope of the echo motion line passing through both P_b and P_e (fig. 6).

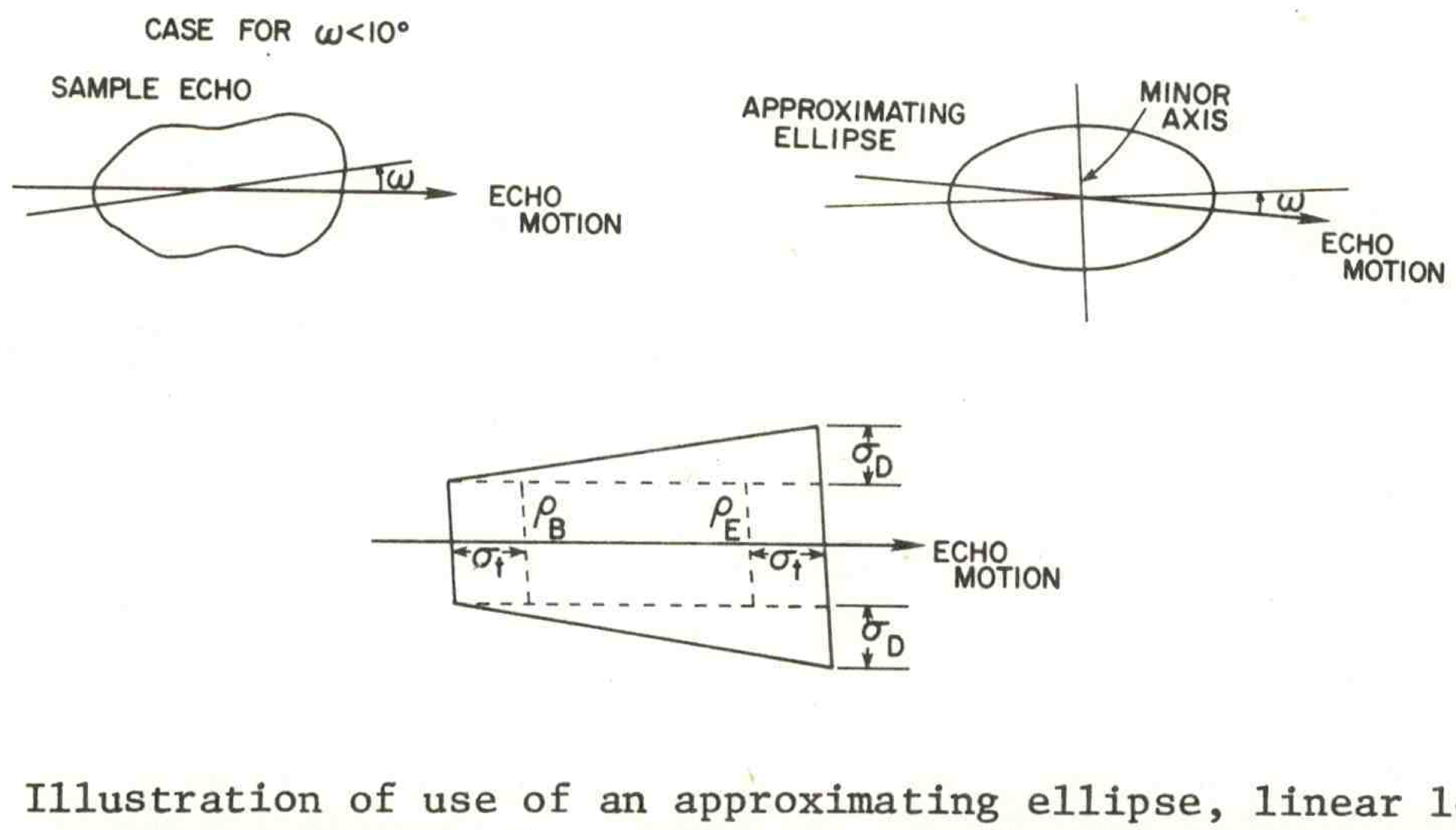

Figure 6. Illustration of use of an approximating ellipse, linear least squares predicted echo trajectory and the RMSE values to calculate graphic warning area for $\omega \leq 10$ degrees.

5. REAL TIME SYSTEM AND PROGRAM OPERATION

Since the remote radar display system has the built-in capability to be interfaced to a computer, we adopted the programming philosophy of duplicating, as nearly as possible, a real-time operation. In this section we shall first describe a model system and its components; second, describe the decision making and choices within the software available to an operator; and third, offer some guidelines for using the program logic.

5.1 Hypothetical Systems Configuration

In addition to the electronic components already described in Volume I, the system requires a central processor with a 50K decimal word memory core. In order to operate in a pseudo-real-time manner, memory cycle time should be about one μsec. (The Systems Engineering Laboratory's model 8600, on which the software was developed, has a memory cycle time of 600 nanosec.)

Secondly, some sort of mass storage unit is needed. When not being used, the prediction and display logic resides there. Otherwise, the Fortran program would have to be entered each time the system is used. Also stored on disk are three data files: a) coordinates for graphically displaying the State of Oklahoma, b) coordinates for graphically displaying the Victor Airways, and c) a list of Oklahoma airports. (The use of these files is explained below.) Last, an I/O device such as a teletype or alphameric CRT with keyboard entry is needed. The operator must manually insert commands and echo information into the software and, in turn, receives back numerical values of echo speed and direction of motion and a measure of the predictability of echo motion. Information flow is shown in the systems flow chart (fig. 7).

5.2 Hypothetical Software Logic

First, let us assume that the program already resides on disk and has been given the name ECHOPRED. The operator then merely enters ECHOPRED to bring the program to an operational status. The operator's first decision is whether or not to initialize the program. (Figure 8 illustrates the command structure which is presented in this section.) This depends upon whether or not the operator is working a new storm day. For a new day or a long break in operation, the operator's response will be 'YES', otherwise we presume he is still working the same storms and the response is 'NO', to the question, 'INITIALIZE'. When the answer is 'NO', echo information is retrieved from disk. The program should be left operational during storm conditions; only if a power failure disrupts operation should the operator not initialize the program.

Next, the program will ask for 'COMMAND'. Assuming this is the start of operation or recovery after a failure, a systems check should be made. After the operator responds with 'RQC', <u>R</u>adar <u>Q</u>uality <u>C</u>ontrol,

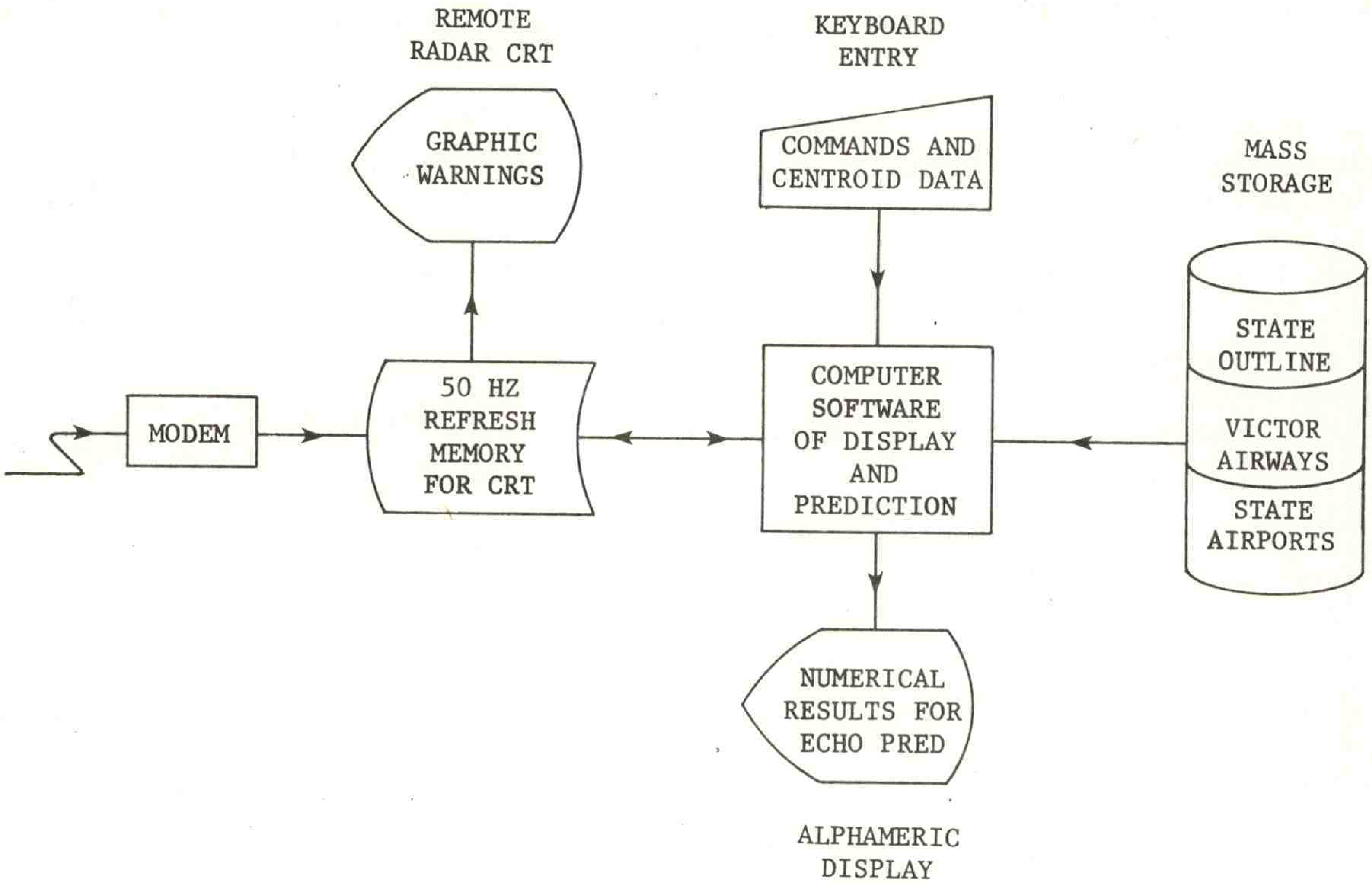

Figure 7. Schematic of systems flow chart.

the computer will type first 'PPI CHECK' with appropriate response being 'YES' or 'NO', and then 'TEST PATTERN'. Again the operator responds 'YES' or 'NO'.

In 'PPI CHECK' the program checks the housekeeping information (date, time, azimuth) in detail and also counts the number of bins of each intensity in the PPI and presents this information to the operator. A systematic decrease in the frequency of higher intensities should occur when only ground clutter returns are present. A low count at especially the first, second or fourth intensity levels may indicate hardware failure. A few random housekeeping errors will occur due to telephone line noise and are not serious.

The 'TEST PATTERN' is a computer generated field of seven concentric rings 20 degrees in width corresponding to each intensity switch surrounded by seven radial stripes of 10 degrees width starting with 0 degrees AZM, and repeated through 360 degrees. The purpose is to check the fidelity of the receiver memory. For least confusion, we recommend setting the intensity switches to the following gray shade pattern: 1 2 3 1 2 3 2.

When the computer has finished with one or both of the above tests, it will again type 'COMMAND'. At this point the operator may wish to enter a value for the Time Weight Constant, TWC. After TWC is entered, the computer will type 'HHMM' for which the operator enters a number such

Figure 8. (Here and on adjoining page) Illustration showing various commands used in ECHOPRED.

```
INITIALIZE
YES
COMMAND
RQC
PPI CHECK
YES
TEST PATTERN
YES
 IAZ TILT STC JUL   TIME DLY GL TC
   0    0    0 164 110025   0  1  1

LAST AZIMUTH = 359 LAST RADIAL = 360

INTENSITY BIT COUNT
        1          2          3          4          5          6          7
      844       1085        803       1128        686        494          0

SET INTENSITY SWITCHES TO 1 2 3 1 2 3 2

COMMAND
TWC
HHMM
  30

COMMAND
GCD
20

COMMAND
ACC

AREA/INTENSITY
 100     3

DAY/ TIME/ TILT
164  1110     0

2 STR ECHOES FOUND WITH AREA GREATER THAN 100 SQ KM

AREA/AZIMUTH/RANGE
 170     334   142
 146     350   137

DAY/ TIME/ TILT
164  1120     0
STOP

2 STR ECHOES FOUND WITH AREA GREATER THAN 100 SQ KM

AREA/AZIMUTH/RANGE
 205     337   137
 144     354   133

COMMAND
ENT
```

```
N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/  STDDS/  STDTM

1 1110 334. 142.
2 1110 350. 137.
1 1120 337. 137.
                          279.9   53.1   0.00   0.000
2 1130 337. 137.
                          285.0   61.4   0.00   0.000
0

COMMAND
DIS
BTIME/ETIME/RANGE/OVERPLAY/ECHO NUMBERS
1120 1220  100  VIC     1    2

WHE
ECHO NO/ AZM/ RNG
      1  19. 104.
12.4  KM(+/- 0.0)  AT 1302   (1211 - 1354)

COMMAND
AIR
BTIME/ ETIME/ STD DEV/ ECHO NO.S
 1120 1220   3.    1    2

ECHO   1

TIME AIRPORT          DIST      FTIM LTIM
NO ENCOUNTERS PREDICTED

ECHO   2
TIME  AIRPORT         DIST       FTIM LTIM
1151  PERRY          3.2 S    1147 1154

   1 ENCOUNTERS LISTED

COMMAND
POS
ECHO NO/ HHMM
    2 1200
AZM.RNG =  11.9 124.4  RAD  1SD=  0.0   RAD 3SD=  0.0

COMMAND
DEL
WHICH ECHOES
    1    2
* NO ACTIVE ECHOES

COMMAND
IGN
 ECHOES 1 AND 2 WERE DELETED BECAUSE THEY WERE NOT STRONG ENOUGH TO
 CONSTITUTE A HAZARD TO AVIATION.
KEY

COMMAND
BYE
```

as 2400. If no entry is made for TWC the program uses a 30 minute default value. The TWC exponentially weights the influence that past centroids have when predicting echo motion, giving greatest weight to the most recent point (see section 5.3.1).

Another parameter the operator may wish to change is the Ground Clutter Distance, GCD. The default value is normally set at 20 km for the NSSL radar, to omit all of the ground targets from the analysis. When the ground clutter is extended by abnormal propagation, spurious echoes may be processed. By setting the size and intensity criteria high enough, these echoes will be ignored. However, time will be lost determining this fact. As echoes move into the ground clutter, spurious echoes will complicate the shape, but not seriously affect total echo area and centroid position. Here a simple and expedient method is to tilt the radar antenna at two degrees which will effectively remove the ground targets from the scope while leaving the echo pattern mostly unchanged. When anomalous echoes are extensive, some program speed-up can be realized by setting the GCD value artificially large, say 100 km. However, the risk here is that the operator will fail to reset the value as echoes approach that range.

The next command by the operator instructs the computer to accept the remote radar data and locate echoes. Before doing this the computer will reply 'AREA/INTENSITY'. The operator must then respond with two values, for example, 100 km^2 and the 4th code switch. This means that only echoes whose areas are greater than 100 km^2 and whose intensities are greater than or equal to the dBZ value corresponding to the fourth intensity switch are contoured. For the data used in this report the dBZ value is about 40--a rainfall rate of 12 mm hr^{-1} (0.5 in hr^{-1}). The program also checks for echoes whose area is five times that given. Whenever this occurs the lowest intensity in the echo is purged and the next intensity level checked to see if it meets 100 km^2 criterion. If it does, the information for the higher intensity core is saved as well as the lower intensity.

At the completion of the PPI, the computer writes out each echo's area and centroid location (azimuth and range); the echoes being sorted by intensity. The program will continue to accept new PPI information unless interrupted by a 'STOP' command typed in by the operator. The program does no matching of echoes between two PPI's and no information from a previous PPI is saved in the computer except that manually entered by the operator. Since two centroid positions are required to make a prediction, the operator should wait two scans before entering time, azimuth and range data.

When the program has received a 'STOP' command, it will ask for a new command. The operator will then want to enter the echo information. This is done by first typing 'ENT'. The computer will then ask for an echo number, time of observation and echo azimuth and range; it will type the following:

'N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/ STDDS/ STDTM'

The echo may have any number assigned between one and 99. The time is entered as a four digit number. The first two digits are for the hour (a 24-hour day is used); the second two digits are for the nearest whole minute. Azimuth is entered to the nearest whole degree; range to the nearest kilometer. After the first two entries and each subsequent entry for the same storm, immediately following, the program will respond with a speed, direction of motion and the standard deviation in distance and time of the echo's motion (cf section 4). The program checks the manually entered data for simple entry errors. Also, if the last time entered is the same as the time of the last PPI scanned by the program, the program will match the manually entered centroid position to the computer derived centroid position. The echo selected is the one whose centroid distance is a minimum from that manually entered. If no match is found, the observation is deleted and an error message generated. If the computed echo speed is greater than 120 km/hr and error message is also typed out but the observation is not purged. (Echoes moving at that speed are rare.) When there are no more observations to enter, the operator enters a zero for the echo number; the program will respond by asking for a new command. One last operation which can be performed is to delete an observation by entering a minus sign in front of the echo number followed by time and centroid positions. Up to ten different echoes can be stored at one time.

There are four different commands the operator may wish to give the program now. They are 'DIS', 'WHE', 'AIR', and 'POS'.

When 'DIS' is entered, the operator has asked for a graphic display of projected storm motion on the remote terminal. The program will ask for a prediction time interval, a specified range, a graphic overlay, and the operator assigned numbers of echoes that the operator wishes to see. The computer will type:

'BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS'

BTIME and ETIME are the beginning and ending times for the prediction period entered in the same four digit format as for entering echo time data. A useful beginning time might be the time of the last PPI and the ending time might be one hour later. RANGE lets the operator choose between a 200 or a 400 km range. If radar data were previously being transmitted at one range, the operator would probably also want the graphic display to be scaled the same. There are two choices for 'OVERLAY'. They are the Oklahoma State outline entered as 'STA' and the low level Victor Airways entered as 'VIC'. Esthetically, the former is more suited to 400 km range, while the latter to a 200 km range. If that entry is left blank, no overlay is produced on the remote radar scope. The ECHO NUMBERS are those assigned by the operator.

Another option is to ask WHEn the centroid of a storm will be nearest a given point. After the operator has entered 'WHE' the program will type:

'ECHO NO/AZM/RNG'

The operator then enters the appropriate information, where AZM and RNG give the position of the point in question, not the centroid of the echo. The computer will return the distance from the point normal to the extrapolated echo path and the standard deviation of that distance. Time of arrival and two other times, one before and one after the predicted time, are also computed. These times are $t \pm \sigma_t$.

Another option available to the operator is to ask for the AIRports which lie in the echo path. The echo path is considered to be a cone whose apex is the centroid position at the time of the last observation. The cone expands downstream as a function of time (fig. 9)* After 'AIR' has been entered as a command, the computer responds by typing

'BTIME/ETIME/STD DEV/ECHO NO.S'

BTIME and ETIME are enterable for DIS. STD DEV is entered as a whole number (e.g., 1, 2, or 3). The expansion rate of the cone is determined by σ_d (STD DEV). ECHO NO.S are the user assigned storm numbers.

The computer will return with the predicted encounters listed by storm in the order of arrival time, t_a. Also given is the distance to the echo path at the arrival time and $t_a + \sigma_t$ and $t_a - \sigma_t$.

One last question the operator may address is, "What will the echo's POSition be at a later time?" After 'POS' has been entered, the computer will type:

'ECHO NO/ HHMM'

The operator enters the required data in the same manner as under the command 'ENT'. After the above information is entered, the computer

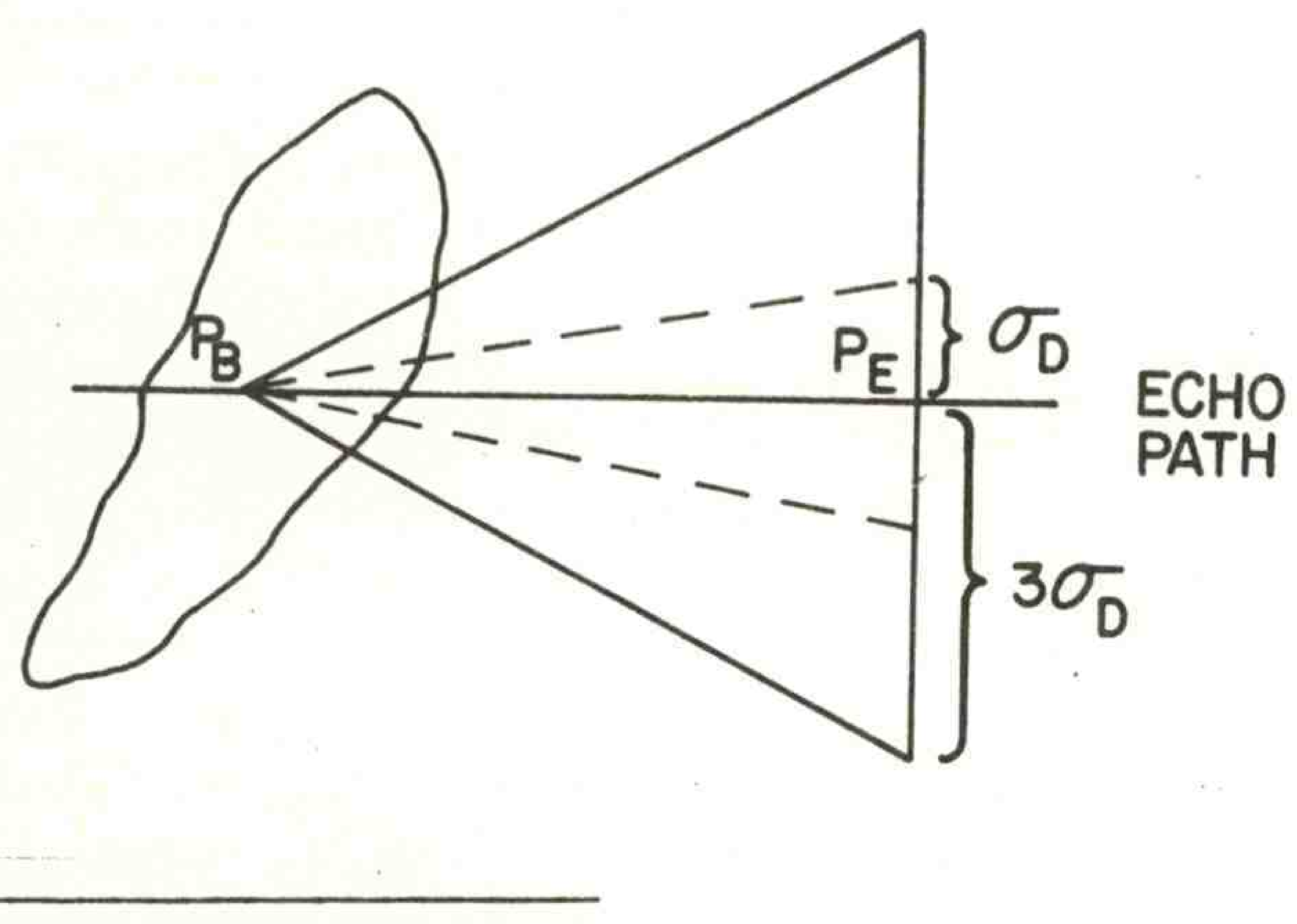

Figure 9. Illustration of cone used to locate airports in an echo's path. Integer 3 was entered for 'STDDEV.'

*Instead of a cone for determining what airports may be affected, the modified parallelogram of the preceding section could be used.

will return the azimuth and range of the centroid for the time given and two values which are σ_d and $3\sigma_d$.

Because computer storage restrictions permit only ten echoes to be tracked simultaneously, the operator will need to DELete echoes from time to time. The operator should consider first those echoes which are no longer being actively tracked.

After entry of 'DEL', the computer asks:

'WHICH ECHOES'

To this the operator responds by entering the assigned echo numbers. Before asking for a new command, the computer lists the active echoes.

On occasion the operator may wish to enter information of a textual nature. This might include severe weather events associated with a particular storm, or storm tendencies for a new operator coming on duty. The command 'IGN' for IGNnore is entered. After this, a text of any number of lines may be entered. To restore the program to an operational mode, the operator types 'KEY' at the beginning of a new line.

To terminate the program, the operator types 'BYE' for a command.

5.3 Some Practical Guidelines for Using Echo Prediction Software

5.3.1 Time Weight Constant (TWC)

At the time the echo prediction logic was developed, it was recognized that severe storms, especially tornado producers, "turn right" as they become severe (Newton and Fankhauser, 1964). In order to take the path curvature into account in predicting future echo positions, an exponentially assigned weighting function was incorporated into the computer software. Mathematically, the function is $W = e^{-k\Delta t/TWC}$ where k is ln 2, TWC, the value entered by an operator and Δt the time interval between two observations. The rate of decay is a function of time (fig. 10) such that when the time elapsed from the last point entered is equal to TWC, the value of the previous point is decreased by half. Although the prediction logic was operationally tested in 1969 and 1970, TWC was always made large enough (24 hours) such that $W \approx 1$. In other words, all centroid positions carried the same weight when fitting LLS equations.

As a first step in testing the utility of changing the weighting function, points were arbitrarily entered at 10 degree intervals at a range of 10 km through a 90 degree sector. The sampling interval was entered as five minutes. The results for k = 24 hrs, 30, 15 and 5 minutes are shown in Figure 11a-d. An examination of the figures shows that the greatest improvement in following the data trend is between the 15 and 5 minute weighting function. Of the four parameters, direction, speed, standard deviation of distance and standard deviation of time, the latter

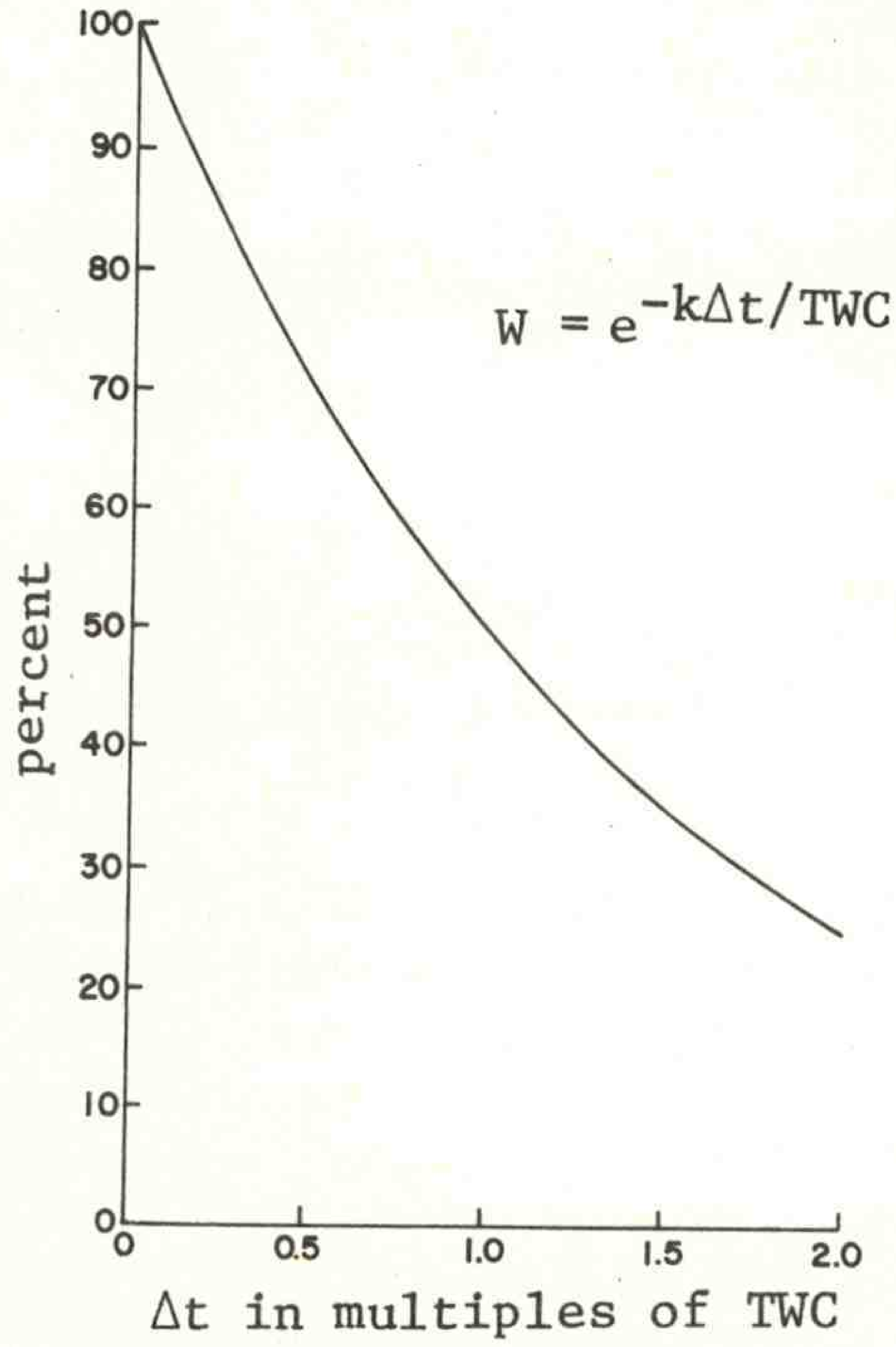

Figure 10. Illustration of response curve for weighting function, W.

showed the greatest overall improvement--nearly a factor of three from .121 hours to .047 hours. Least affected was the speed.

In another test, real data from two storms were used to determine the effects of varying the weighting function. One storm was tracked between 1225Z and 1310Z; the other between 1247Z and 1310Z. Two time weight constants (TWC)--30 and 5 minutes-- were used. Also, because the data density was greater than other cases--2 to 3 minute intervals--two passes at each TWC were made, one at a 2 to 3 minute spacing and the other at a 4 to 6 minute spacing. The results are shown in Table 1. Contrary to the results in the first test, there is little if any improvement in σ_d and σ_t between a 30 and a 5 minute TWC for 2-3 minute spacing. Using 5 minute data spacing and comparing the σ_d and σ_t between a 30 and 5 minute TWC shows some overall improvement. By far the greatest improvement is to use 5 minute data instead of 2-3 minute data. Several sources of error suggest why this is so. One is the natural variability of the echo; that is the random gain or loss of echo due to small scale echo changes. Second, radar system fluctuations of 1-2 dB would cause small scale changes. Third, and perhaps the most important, is the system resolution. Typically, an echo might move 1-2 km in a 2 minute period. At a range of 100 km this might be a change of centroid location of 1 degree azimuth or 1 km range or both. Such a motion results in a very noisy path. Barclay and Wilk (1970) also noted erratic echo movement from centroid positions when using data of similar density. In the remoting system, one must also consider the time element. If one were to use radar data directly and had the time of each radial, the centroid time would be precisely known. However, the time of the data displayed on the remote scope is truncated to the nearest minute so that the time the echo was sampled could conceivably be one minute off. When the truncation error is a large fraction of the ΔT, the projected error from this cause tends to be large.

Let us consider now the speeds and directions actually computed under the different conditions. In general, the TWC had more effect than data density. Echo 1, with TWC equal to 5 minutes, accelerated sharply after 1245 nearly doubling its speed by 1306. With a TWC of 30 minutes, the acceleration is smoothed considerably. The direction also shows considerably more variance with a 5 minute TWC than with a 30 minute TWC. Echo 2 shows basically the same features as Echo 1.

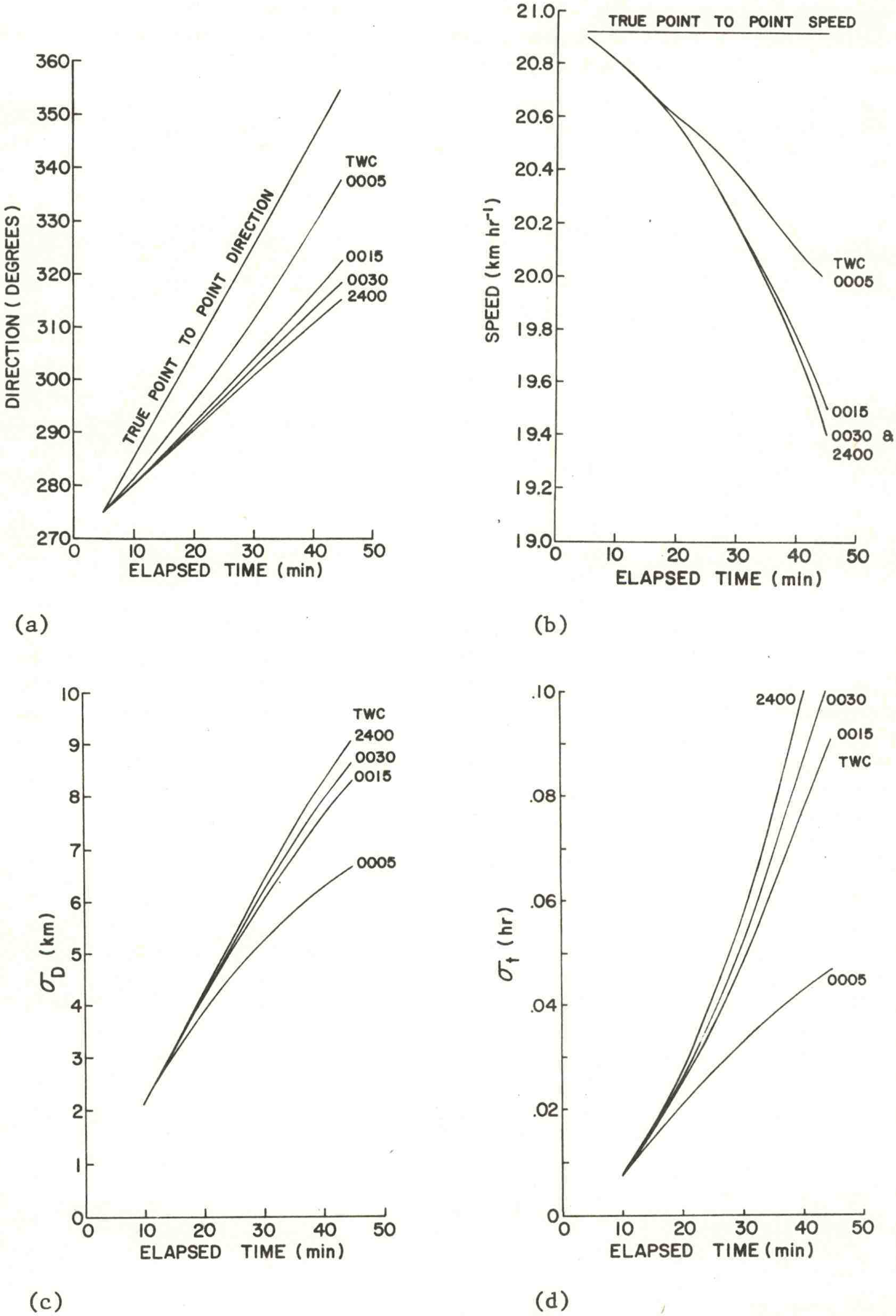

Figure 11. Illustration of the effect of varying the TWC for an echo whose track is curved in calculating (a) direction, (b) speed, (c) σ_d, and (d) σ_t.

Table 1. Comparison of results of using a TWC of both 30 and 5 minutes on data sampled at both 2-3 minutes and 4-6 minutes for tracking two echoes.

	TWC = 30 MIN				TWC = 5 MIN			
				ECHO 1				
				2 MIN DATA				
TIME	DIR	SPD	STDDS	STD TM	DIR	SPD	STDDS	STD TM
1230	254.6	23.8	27.41	.803	247.3	24.3	27.41	.803
1236	273.8	37.6	39.05	.662	272.1	39.2	40.64	.614
1240	258.7	34.6	37.54	.624	252.2	34.6	38.67	.583
1245	253.0	36.1	33.66	.609	248.4	37.9	34.59	.579
1251	238.5	39.7	40.65	.570	227.9	44.7	39.87	.546
1255	228.7	43.2	41.17	.620	216.0	52.0	38.63	.594
1300	224.8	50.5	42.34	.670	219.2	62.3	41.19	.612
1306	218.8	55.4	47.77	.661	210.3	67.6	45.60	.602
1310	219.3	55.1	49.99	.695	217.0	58.4	47.67	.655
				5 MIN DATA				
1230	251.0	24.0	0.00	.000	251.0	24.0	0.00	.000
1236	273.9	36.4	14.10	.394	276.2	38.8	14.10	.394
1240	263.4	34.1	18.90	.410	259.4	34.0	19.20	.429
1245	257.1	36.7	17.63	.403	252.2	38.8	17.52	.422
1251	238.4	39.3	28.34	.368	223.6	45.7	27.20	.386
1255	228.2	43.6	31.01	.405	214.7	53.6	27.09	.415
1300	227.0	48.7	29.75	.448	222.3	60.1	28.25	.397
1306	220.9	53.0	32.47	.436	211.2	65.6	30.34	.377
1310	220.7	53.6	32.62	.437	216.6	58.7	31.25	.412
				ECHO 2				
				2 MIN DATA				
1230	-	-	-	-	-	-	-	-
1236	-	-	-	-	-	-	-	-
1240	-	-	-	-	-	-	-	-
1247	346.1	74.1	0.00	0.000	346.1	74.2	0.00	0.000
1251	270.7	38.9	62.34	1.099	268.6	36.3	62.06	0.944
1255	247.0	41.7	57.18	1.020	241.1	42.1	56.50	1.049
1300	233.5	66.4	56.79	1.362	230.9	73.9	53.82	1.372
1306	228.3	74.7	52.68	1.236	226.3	79.8	48.81	1.201
1310	229.6	70.0	48.35	1.146	230.4	66.3	45.93	1.155
				5 MIN DATA				
1230	-	-	-	-	-	-	-	-
1236	-	-	-	-	-	-	-	-
1240	-	-	-	-	-	-	-	-
1247	-	-	-	-	-	-	-	-
1251	286.1	33.2	0.00	0.000	286.1	33.2	0.00	0.000
1255	251.8	38.2	32.21	0.075	245.0	41.3	32.21	0.075
1300	235.8	65.0	36.27	0.912	231.8	78.6	32.46	0.863
1306	231.6	72.0	32.85	0.817	228.9	79.1	29.19	0.774
1310	232.6	66.9	30.79	0.803	232.5	64.5	27.63	0.772

Although two storms are admittedly a small sample, our experience in a large number of cases makes us believe that these results apply to other storms as well. Essentially, what is indicated is that for a five minute forecast of echo motion, one should use a five minute TWC, with five minute data resolution. However, for a 30 to 60 minute forecast, a larger TWC, such as 30 minutes, should be used. Over this length of time, trends in the overall echo motion are more important than short term fluctuations which should be smoothed out. Also, since warning areas are mapped out based on echo speed and motion, large variance from one time to the next would only confuse the user and cause the warning areas to shift considerably from one prediction PPI to another.

5.3.2 Selection of Area and Intensity Criteria

In choosing the threshold area and intensity the user is hampered by being limited to ten echoes. However, the ability to assimilate and follow even ten is questionable. On a scope containing many echoes, therefore, the user's attention should be directed to the largest and/or strongest echoes.

Barclay and Wilk (1970) determined that for echo extrapolation using centroid data, threshold values of 10^3 to 10^4 mm^6m^{-3} for isolated storms and 10^2 to $10^3 mm^6m^{-3}$ for squall lines worked best. Based on his own experience, the author believes these are good criteria. With higher intensities, tracking is difficult because the lifetimes of the intense cores are short and in squall lines the probability of mergers and splits also increases. If one uses too low an intensity, information concerning those areas most hazardous to aircraft is lost. A general rule-of-thumb is to use the lowest intensity for which a discrete echo can still be defined.

In a master's thesis in 1969, R. A. Houze, Jr. defined three areal sizes associated with New England precipitation: "synoptic scale areas" on the order of 10^4 - 10^5 mi^2 and a duration of about 10 hours to pass a point; "mesoscale areas" on the order of 10^2 - 10^3 mi^2 and a duration of about one hour; and "cells" with a 1-10 mi^2 area and lasting about one minute. The scale size which is associated with severe weather and with which we have concerned ourselves in this report, is the mesoscale. The synoptic scale pattern is dependent on larger atmospheric disturbances and its movement is better forecast by existing NWS software. Also, the average radar intensity does not constitute a hazard to aviation from strong shear or turbulence. Small, intense cells, on the other hand, are of too short a duration to be tracked and where they do occur--imbedded in mesoscale systems--the entire area should be avoided.

The average area of eight extremely severe isolated storms which have occurred in Oklahoma over the past six years was 208 n mi^2 (713 km^2) with a range of 122 to 427 n mi^2. Squall lines generally are about three times the size of isolated echoes, although cells within squall lines are usually slightly smaller than severe, isolated storms. Since the areas given above are for total storms, the actual area threshold used is reduced by a factor of 2 or 3 depending on the intensity threshold. In summary, the area threshold ranges between 100 and 1000 km^2, while the intensity varies from $10^2 mm^6 m^{-3}$ to $10^4 mm^6 m^{-3}$. Experience guides determination of the best combination for any given storm system.

Once the criteria are established, the user is well advised to resist frequent change. The purpose in establishing criteria is to give the user a history for summarizing events on the display. Frequent changes will cause loss of continuity of pattern.

If it becomes difficult to match echoes due to frequent splitting or merging, however, then a lower intensity and a larger area should be selected. Conversely, if persistent significant core elements are being omitted, then higher intensity and smaller area threshold are indicated.

5.3.3 Splits and Mergers

One of the biggest problems in using echo centroids to track and extrapolate future positions is how to handle splitting or merging storms. For example, if a storm splits into two distinct cores, should you regard one of the cores as a continuation of the old echo and tag the other core as a new echo or should both be treated as new echoes? A similar problem exists with mergers.

The best procedure the author has found is to follow trends in area and centroid position for each core in question. Typically, in a five minute period, an echo will move from 3 to 6 km. If motion is along a radial, then the centroid position is simply a function of range. If, however, the azimuth changes, then the incremental change is range dependent. Figure 12 shows the change in azimuth as a function of range for motion tangent to a circle at that range. The important consideration remains to look for discontinuities in either range or azimuth. A change in range 10 km and/or 10 degrees greater than expected coupled with a 20 percent or greater change in area, should be considered a new echo.

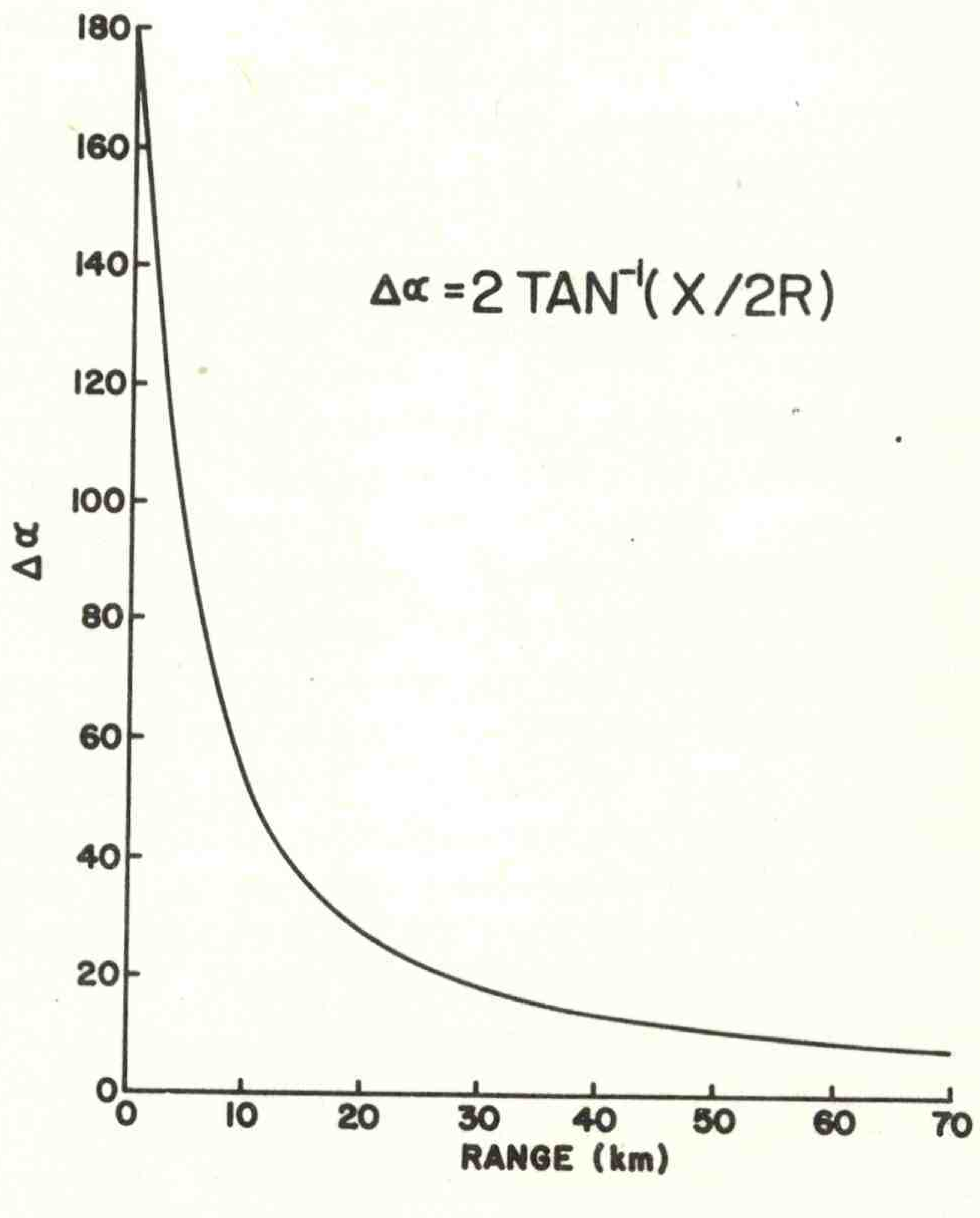

Figure 12. Illustration of the angular change in centroid position as a function of range. X is the displacement distance of the centroid.

6. TEST CASES

Three days were selected for program testing. On two days, June 6 and June 16, 1975, squall lines producing damaging surface winds moved across the State; the third case on November 2, 1974, produced localized flooding in the northwest Oklahoma City with cumulative rainfall amounts in excess of five inches.

The three cases above were chosen because of their danger to the aviation community. In the case of fast moving squalls, the inherent danger is from the turbulence and high winds in and around them. In the case of flooding, aside from the intensity of storms, the sheer persistence of heavy rain in one location implies time delays for air traffic leaving and/or arriving, or for circumnavigating those features. Certainly, it is of the utmost importance for a pilot, en route, to know of adverse conditions which will not clear his destination by his ETA.

The case studies were made to develop the logic to generate graphic forecasts and to determine the feasibility of using the polar coordinate display as a graphics terminal. The analyses excluded quantitative verification of the predicted echo motion. The cases were analyzed using variations of the echo tracking logic, involving different cutoff limits for magnitudes of σ_d and σ_t in expanding the warning areas.

In simulating real time operations, radar data archived on magnetic tape were reformatted to "look" like data received by the remote radar display program. A second tape was generated by the echo prediction logic which contained the graphics information, also in the format for the remoting system. The graphics tape was then played through a tape drive* and transmitted to the receiver where the graphics were photographed.

There are three components to the graphics: individual warning areas for one or more storms; a contour at a specified intensity threshold for each echo; and a background reference field, showing the Victor Airways or the state outline. Each component is coded at one of three 'intensity' values to produce differential gray shading. Warning areas were coded in the seventh intensity level (not normally used in the real time echo display) and displayed at the brightest gray-shade level; echo contours were coded in the second intensity level and displayed at the medium gray-shade level; and the Victor Airways were coded in the first intensity level and displayed at the lightest gray shade level.

After reviewing the radar data on the remote scope, threshold criteria were selected and an initial run was made using the echo prediction logic. The area and centroid data from this run were matched and a second run was made using these results to generate the warning areas. The following cases illustrate the logic and generation of the graphics.

Case 1, June 6, 1975

A stationary front was indicated on the 12Z surface map (fig. 13) as extending from the Oklahoma Texas panhandles northeastward across the

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*As part of the specifications, a half-inch magnetic tape interface at the transmitter was provided.

southern third of Kansas; a cold front was entering Nebraska to the north. The upper level flow at 500 mb (fig. 14) was from the west-northwest. Storms broke out along the stationary front in Kansas in the early afternoon and generally moved southeast in the same direction as the flow aloft. Abundent moisture was available in central Oklahoma (18-20 g kg^{-1}) and the air was potentially unstable. Surface winds were from the south-southeast at 15-20 knots. By 2000 CST, a well-developed dry line oriented north-south existed in the Texas and Oklahoma panhandles as shown by the surface analysis with streamlines in Figure 15. Cold air produced by the storms in western Kansas had produced a pseudo cold front as well. Therefore, an area of strong convergence formed in northwest Oklahoma (fig. 16). As the Kansas storms were following the same track, growth was favored on the southern flank of these storms and a line formed propagating southward.

As shown in Figure 17, the closest echoes at 1600 were about 200 km away along the Kansas-Oklahoma border. Because the motion at that time was east-southeast, the echoes were not expected to move within Doppler radar range. Hence, operations ceased and, between 1625 and 1830 CST, no radar data were collected. The radar, monitored at 1830 CST, indicated a large echo was still beyond Doppler radar range. Within two hours, significant changes occurred. A line of storms developed in the northwest quadrant and proceeded to move southward into central Oklahoma.

For experimental development of the echo prediction and display logic, analysis was begun at 2040 CST when the echoes were within 120 km. A condensation of echo positions and motions is presented in Table 2. The complete program command structure with annotation is included as Appendix 1. For this storm period, the size and intensity criteria selected were 250 km^2 and code switch 4 (corresponding to 40 dBZ), respectively. Data at 0 degree elevation were available at five minute intervals. The time weight constant was set at 2400 (24 hr) and the ground clutter distance at 20 km.

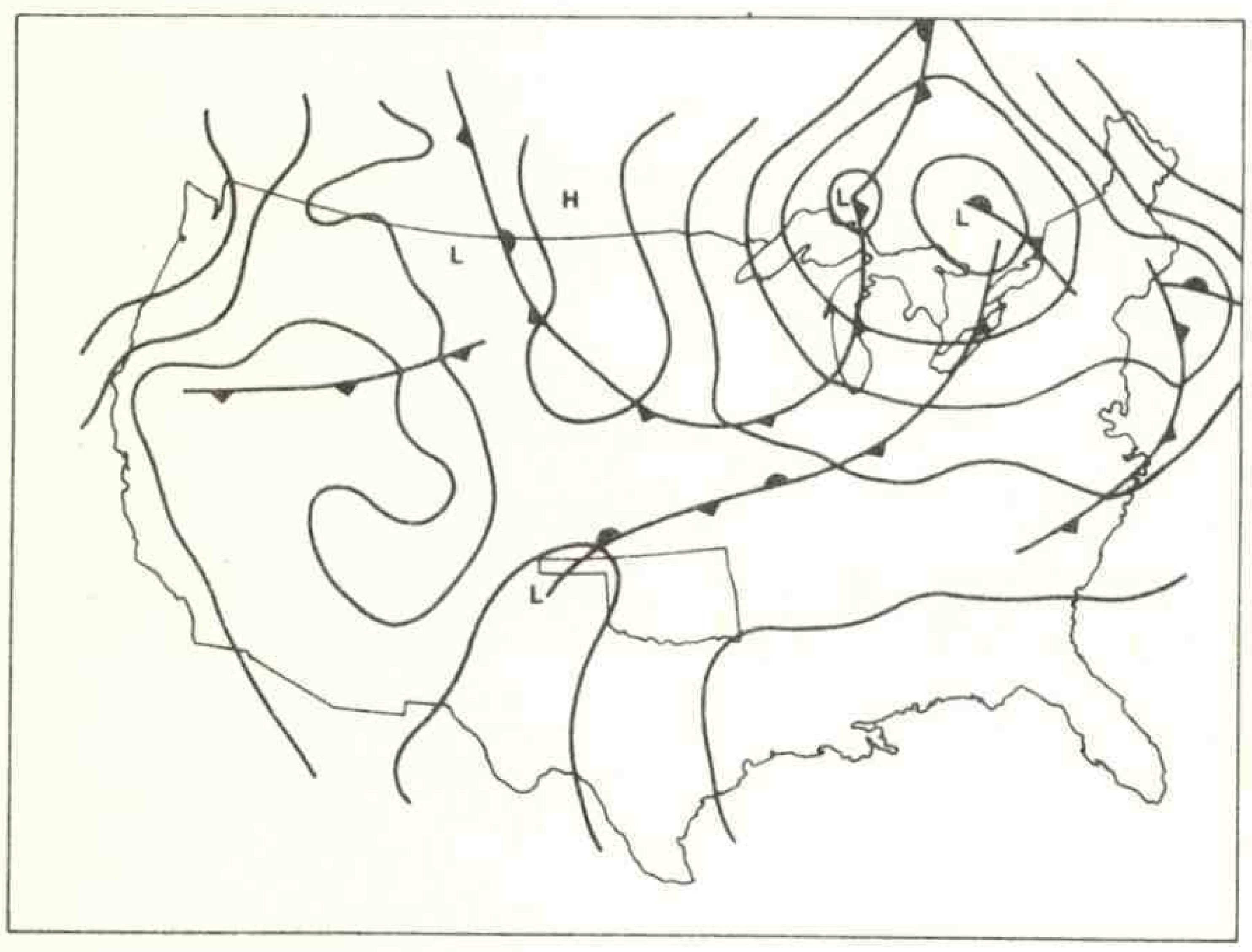


Figure 13. June 6, 1975, 12Z, surface analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

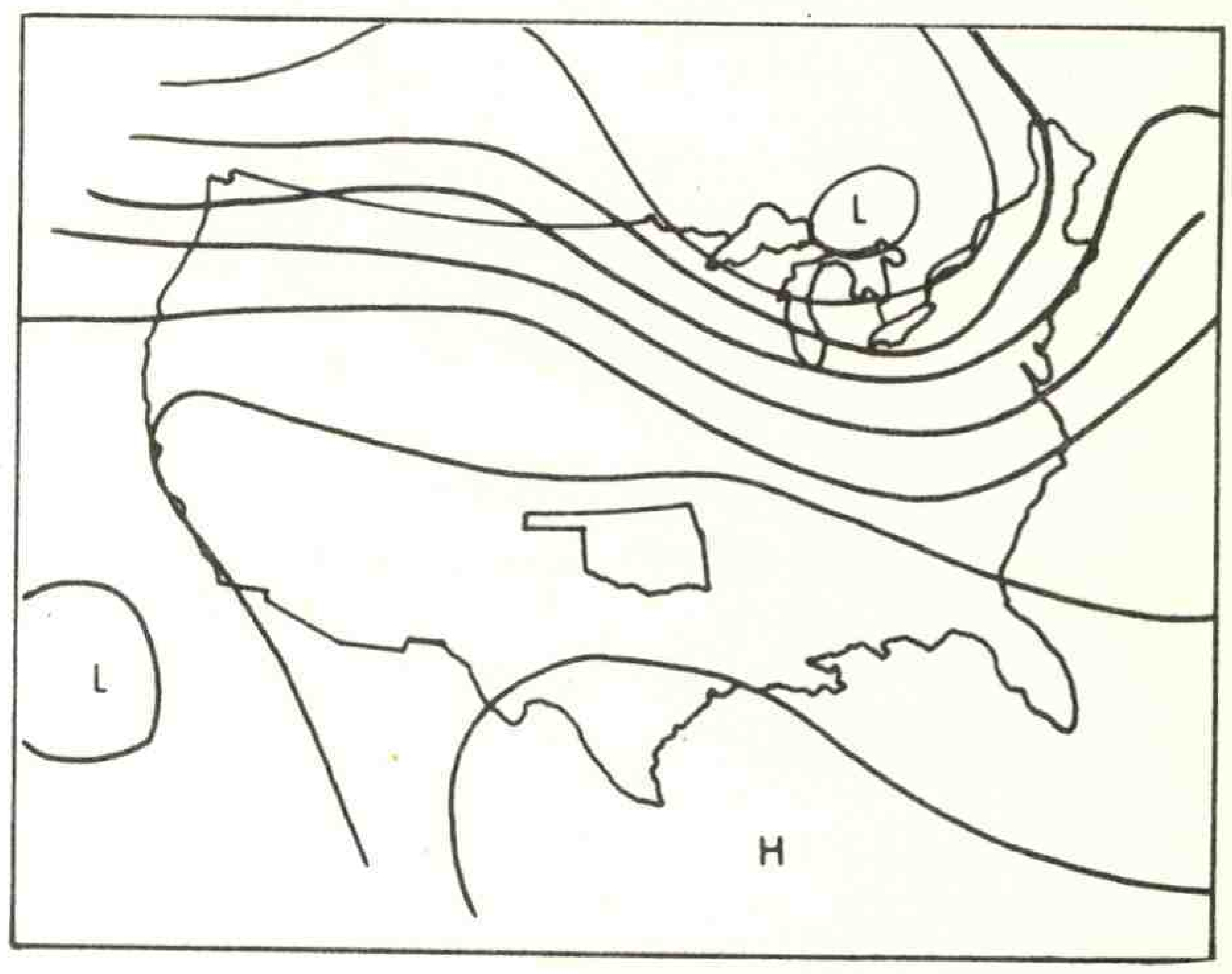


Figure 14. June 6, 1975, 12Z, 500 mb analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

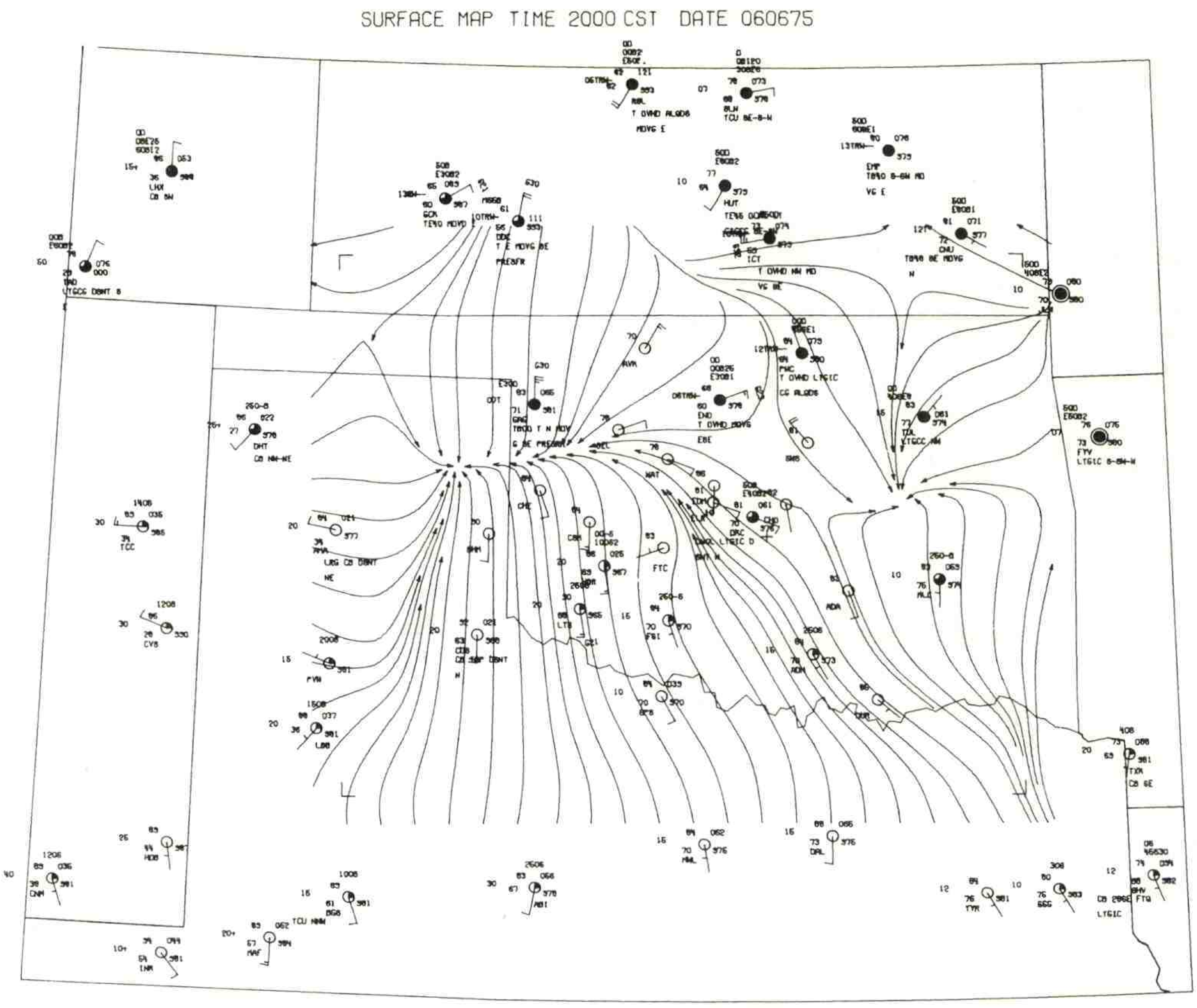


Figure 15. Subsynoptic surface data provided by NWS, FAA and NSSL stations, 2000 CST, June 6, 1975, with streamlines superimposed.

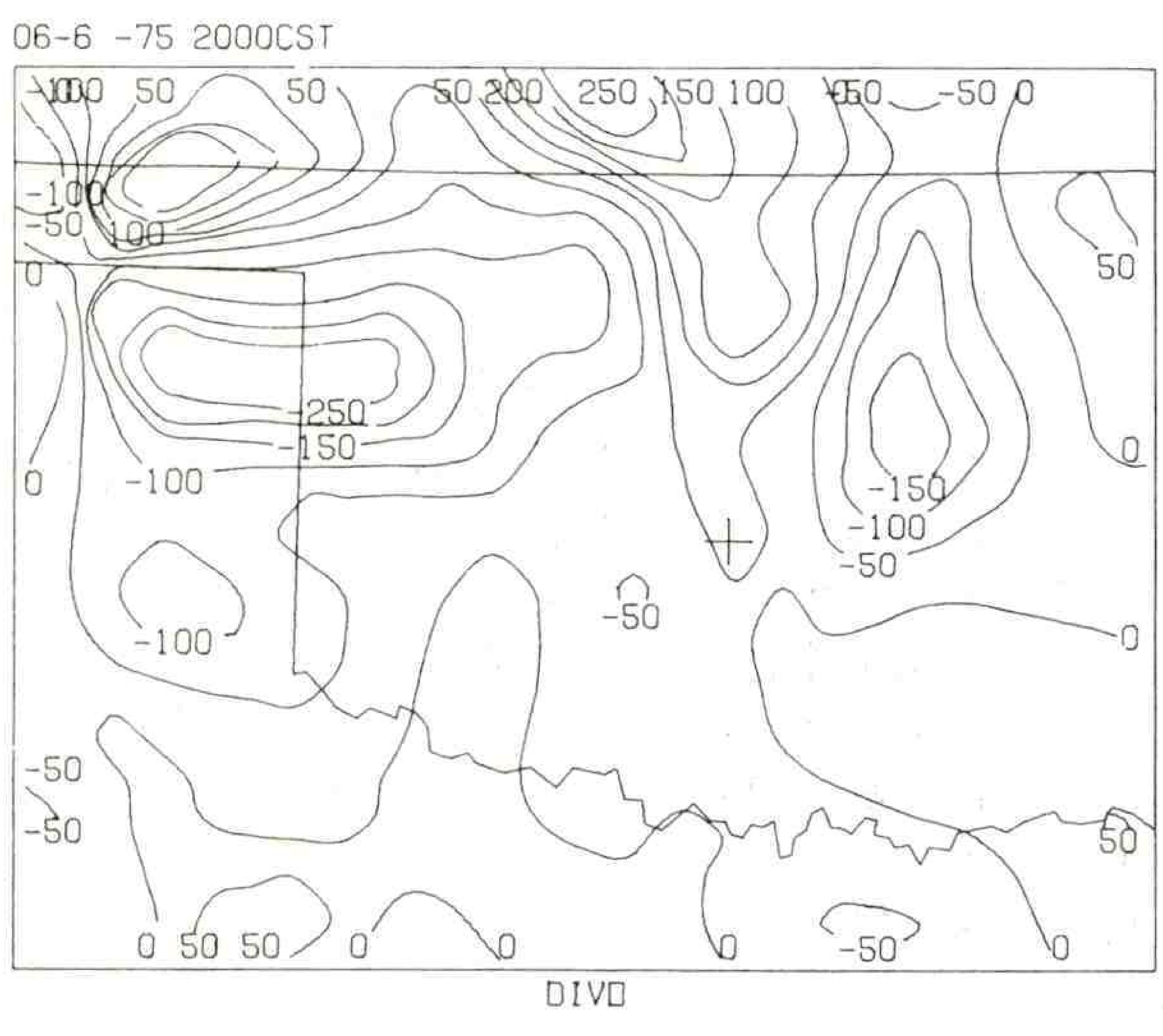


Figure 16. Divergence field derived from surface data, 2000 CST, June 6, 1975. All values are x 10^{-6}.

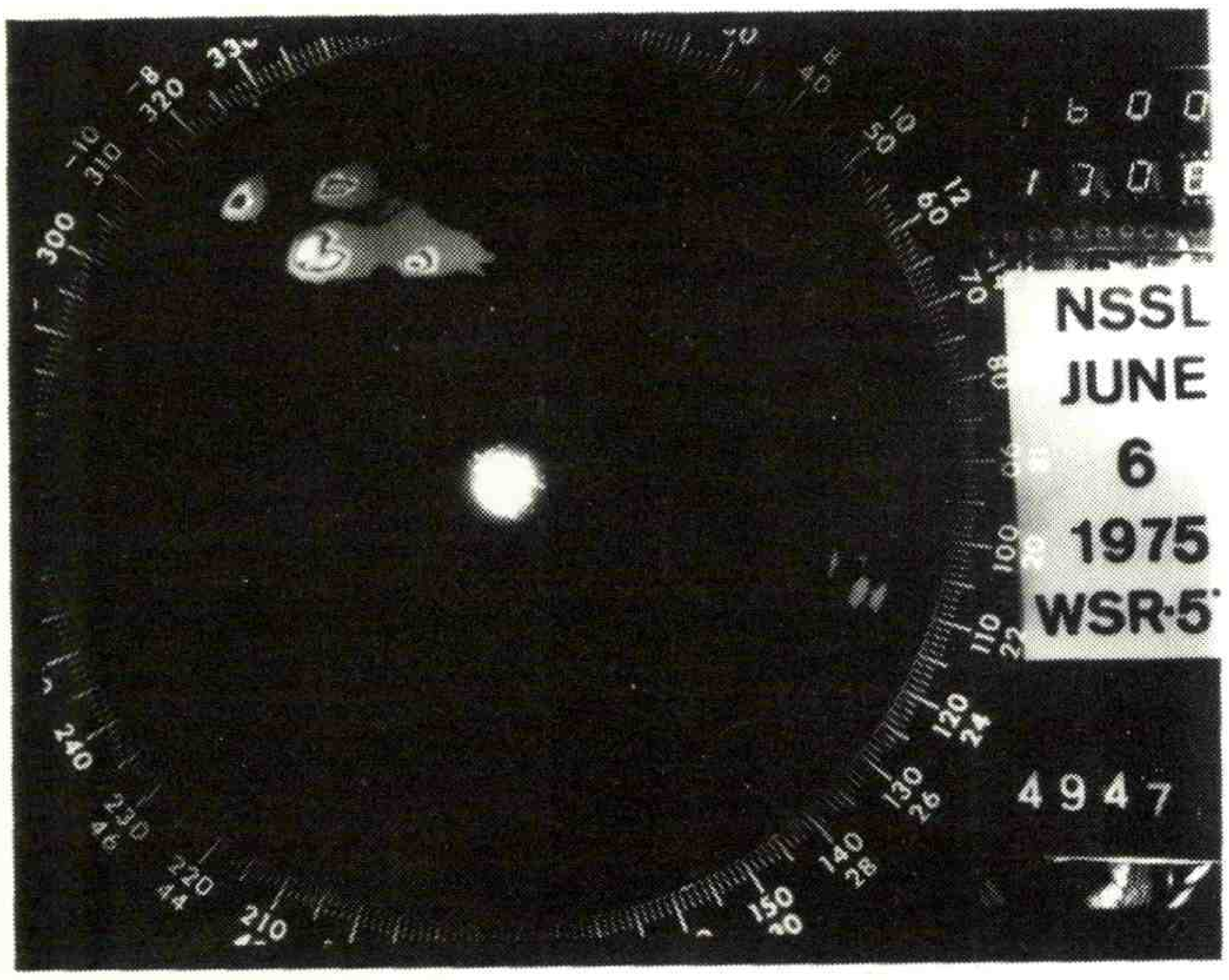


Figure 17. WSR-57 radar PPI, 400 km range, 100 km range marks, 1600 CST, June 6, 1975.

Gray shades for each intensity level were set at 1220333 and resulted in echoes being contoured at cancellation level on the remote scope.

At 2040 CST, as shown in Figure 18, two large cells were located by the computer search at azimuth 29°, range 136 km and at azimuth 335°, range 157 km. After the second PPI at 2045 CST, the same two cells were matched manually to the previous cells. They were labeled echo 1 and echo 2 and their respective times and positions were entered for tracking. Significantly different motions were obtained: echo 1 moved from west-northwest (293°) at 93 km hr^{-1} while echo 2 moved from north-northwest (335°) at 52 km hr^{-1}. Warning graphics were then displayed for these echoes (fig. 19). The starting position for each warning area is 15 minutes after the last observation, the ending position is one hour and 15 minutes later. All subsequent warning areas were also for one hour duration starting 15 minutes downstream. A circle was drawn on the graphics display after the PPI at 2055 (fig. 20) to represent the echo shape. The program does not save echo shape information for more than one PPI. Whenever a graphic display of a warning area is requested for an echo for which no entry was made for the last PPI, a circle with a 10 km radius automatically replaces the initial shape function.

A third echo located at azimuth at 60° range 195 km, at 2050 showed no movement by 2055 CST. The resulting warning area was a line drawn along the major axis of the echo (fig. 20). With the addition of a third point at 2100 CST, an exorbitantly large σ_t was calculated. When the prediction field was first displayed, the large value of σ_t distorted the warning area. Therefore, a "cutoff" limit was introduced such that whenever σ_t exceeded the prediction interval, $t_e - t_b$, σ_t was set to $(t_e - t_b)/2$. Later, a "cutoff" limit was also established for σ_d restricting it to the length of an echo's axis used in defining the warning area. The choice of these limits was purely arbitrary and may need further adjustment based on a large sample of data. Obviously, many tracks, based on the first few observations, will show considerable scatter. As additional locations are added over a larger period of time, a better estimate of the mean velocity will

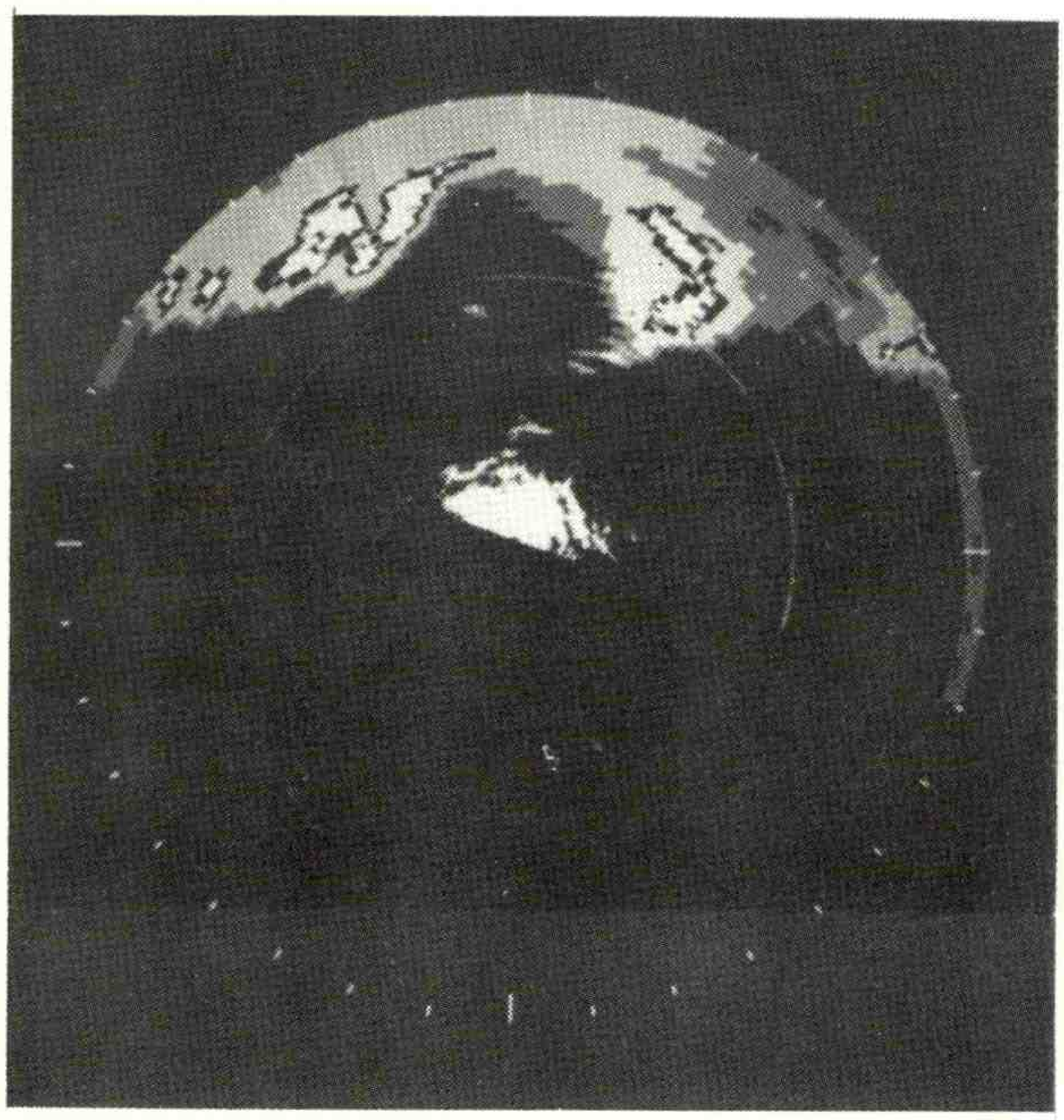
Table 2. Echo centroid positions, direction and speed predicted, and the RMSE values for June 6, 1975.

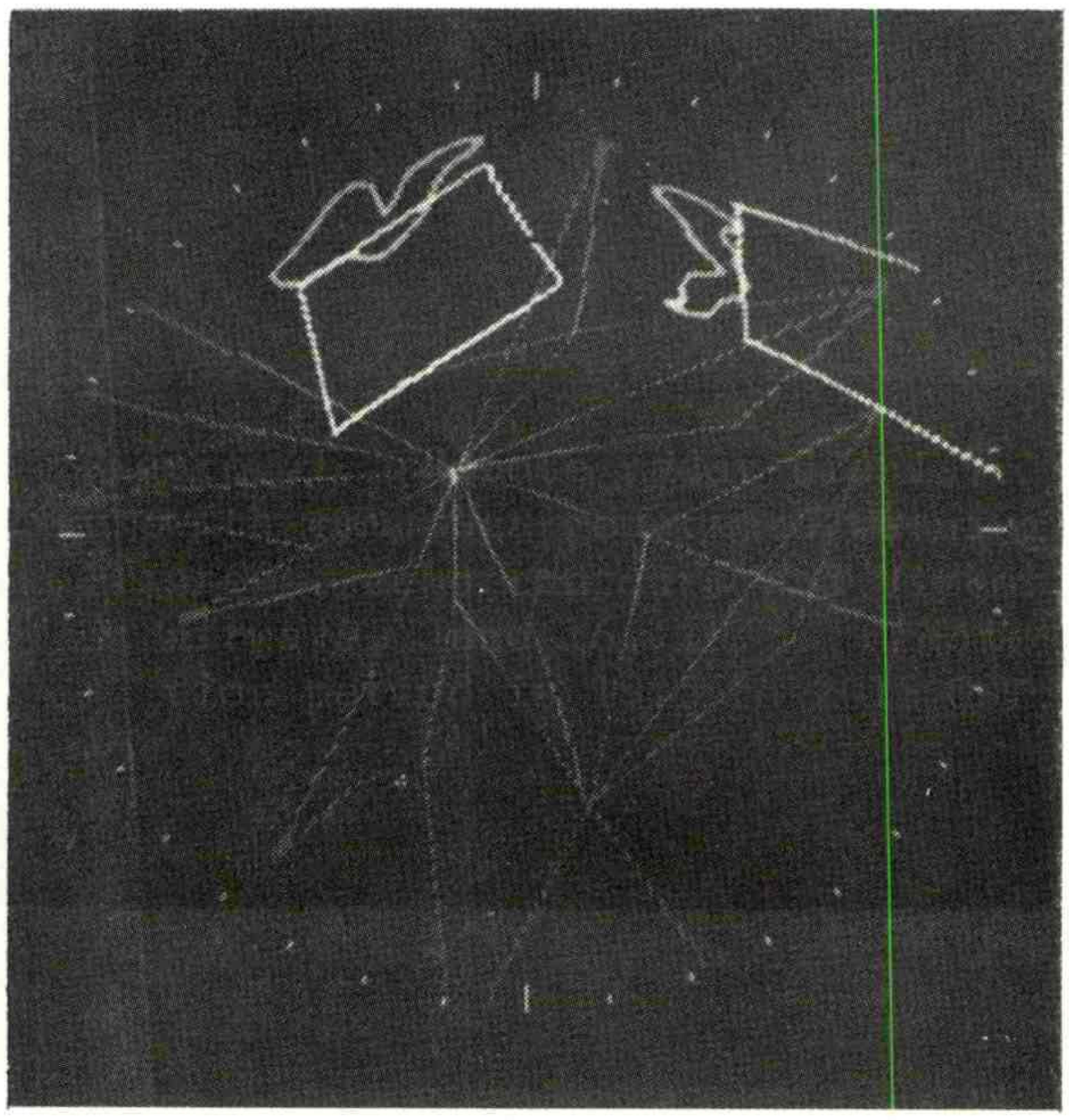
ECHO NO.	TIME (CST)	AZIMUTH (DEGREES)	RANGE (KM)	DIRECTION (DEGREES)	SPEED (KM HR^{-1})	σ_d (KM)	σ_t (HOUR)
1	2040	29.	136.	-	-	-	-
2	2040	335.	157.	-	-	-	-
1	2045	32.	137.	292.5	92.9	-	-
2	2045	335.	153.	335.0	51.5	-	-
1	2050	34.	140.	283.1	78.7	14.36	0.182
2	2050	336.	148.	319.0	58.2	17.90	0.098
3	2050	61.	188.	-	-	-	-
1	2055	36.	144.	276.9	75.9	16.73	0.162
3	2055	61.	188.	360.0	0.0	-	-
1	2100	38.	146.	277.1	73.1	15.58	0.159
2	2100	335.	136.	334.2	64.3	23.26	0.102
3	2100	61.	189.	241.0	6.1	6.06	*
4	2100	298.	194.	-	-	-	-
6	2100	310.	155.	-	-	-	-
2	2105	336.	132.	331.8	62.8	24.05	0.142
3	2105	60.	187.	138.9	12.2	20.27	*
4	2105	297.	192.	356.8	49.0	-	-
6	2105	308.	152.	9.8	76.7	-	-
2	2110	333.	124.	339.1	66.1	40.99	0.230
3	2110	59.	187.	139.7	20.2	18.42	*
4	2110	296.	188.	345.0	55.0	12.69	0.110
1	2115	44.	162.	272.1	79.2	15.85	0.171
2	2115	333.	118.	341.2	68.1	38.06	0.215
3	2115	61.	188.	137.7	8.1	16.84	*
4	2115	295.	184.	340.6	57.4	12.34	0.109
1	2120	48.	160.	277.9	80.7	44.36	0.159
2	2120	334.	115.	340.5	66.6	37.05	0.274
3	2120	60.	189.	153.9	7.1	17.39	*
4	2120	295.	178.	329.4	57.6	25.53	0.112
5	2120	305.	131.	-	-	-	-
1	2125	50.	165.	279.9	82.1	41.50	0.155
2	2125	332.	105.	341.5	69.1	36.33	0.389
3	2125	60.	191.	178.8	7.0	18.34	-
4	2125	296.	166.	312.9	66.7	50.69	0.313
5	2125	305.	126.	305.0	61.0	-	-
7	2125	13.	189.	-	-	-	-
1	2130	50.	173.	278.3	81.8	46.15	0.167
2	2130	332.	101.	341.7	69.5	34.56	0.383
4	2130	295.	163.	310.0	68.5	47.67	0.316
5	2130	304.	122.	318.3	55.8	14.75	0.121
7	2130	12.	187.	71.1	46.1	-	-

*In the run used for generating the graphics the values for σ_t exceeded 99999.999. By deleting the observation for cell 3 at 2055 CST, σ_t was reduced to about three hours.

be made. At 2105 CST three cells were associated with the squall line (fig. 21). Generally, the core in the middle cell in the line was too small to be tracked.

No major changes occurred in the pattern but several more PPI's and graphics (figs. 22-27) on this data are presented as examples. The last PPI at 2130 CST and graphic warning areas which were displayed at a 400 km range with the State outline. The last radar PPI at 2249 CST (fig. 28) (about the ending time of the last warning area) shows that the line had moved as expected.





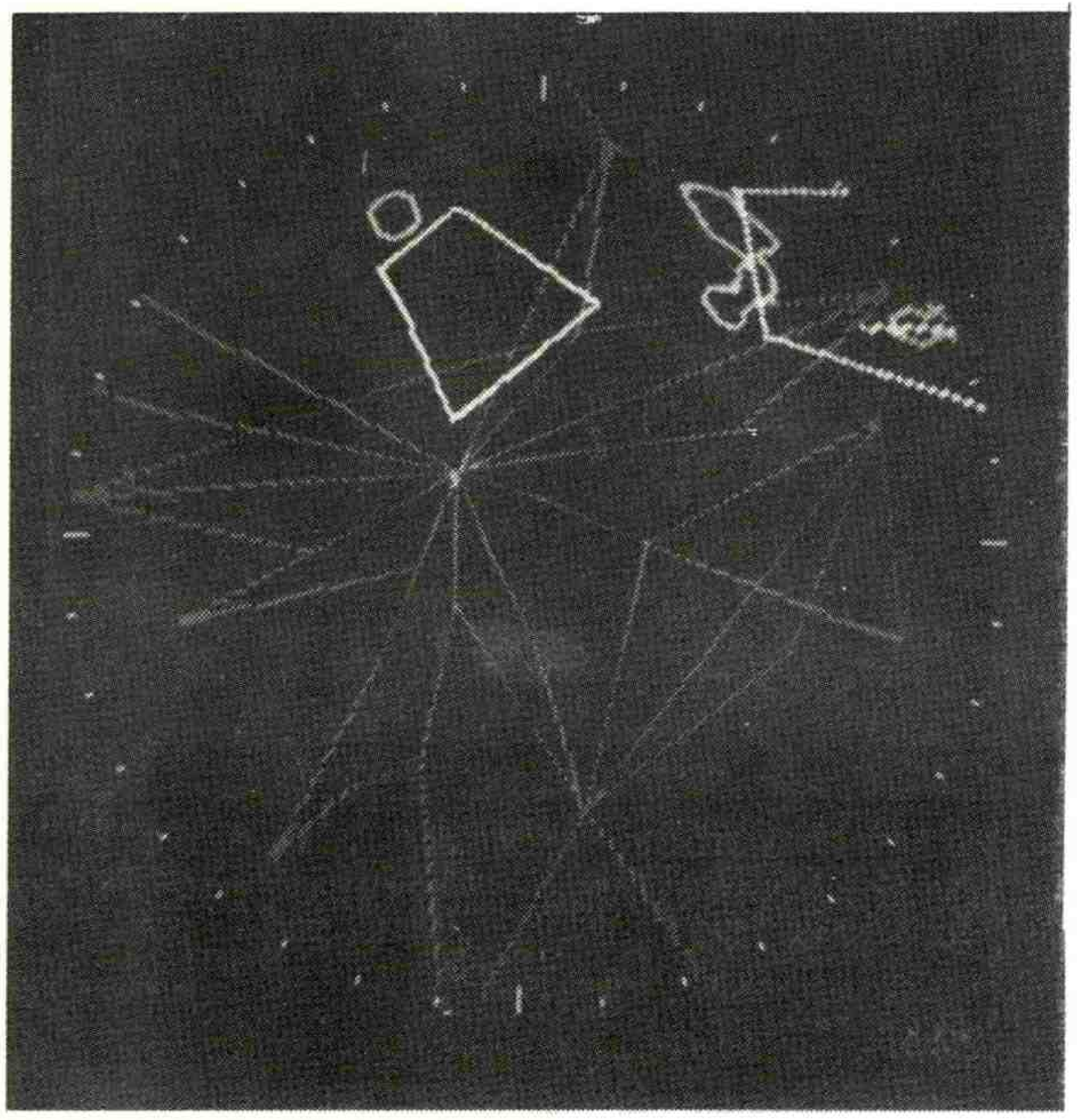


Figure 18. (left, above) Remote radar display PPI, 200 km range, 2040 CST, June 6, 1975.

Figure 19. (above) Remote radar display with computer generated warning areas, echo contours and Victor airways, June 6, 1975. Prediction period is 2100 to 2200 CST.

Figure 20. (left) Remote radar display with computer generated warning areas, echo contours and Victor airways, June 6, 1975. Prediction period is 2110 to 2210 CST.

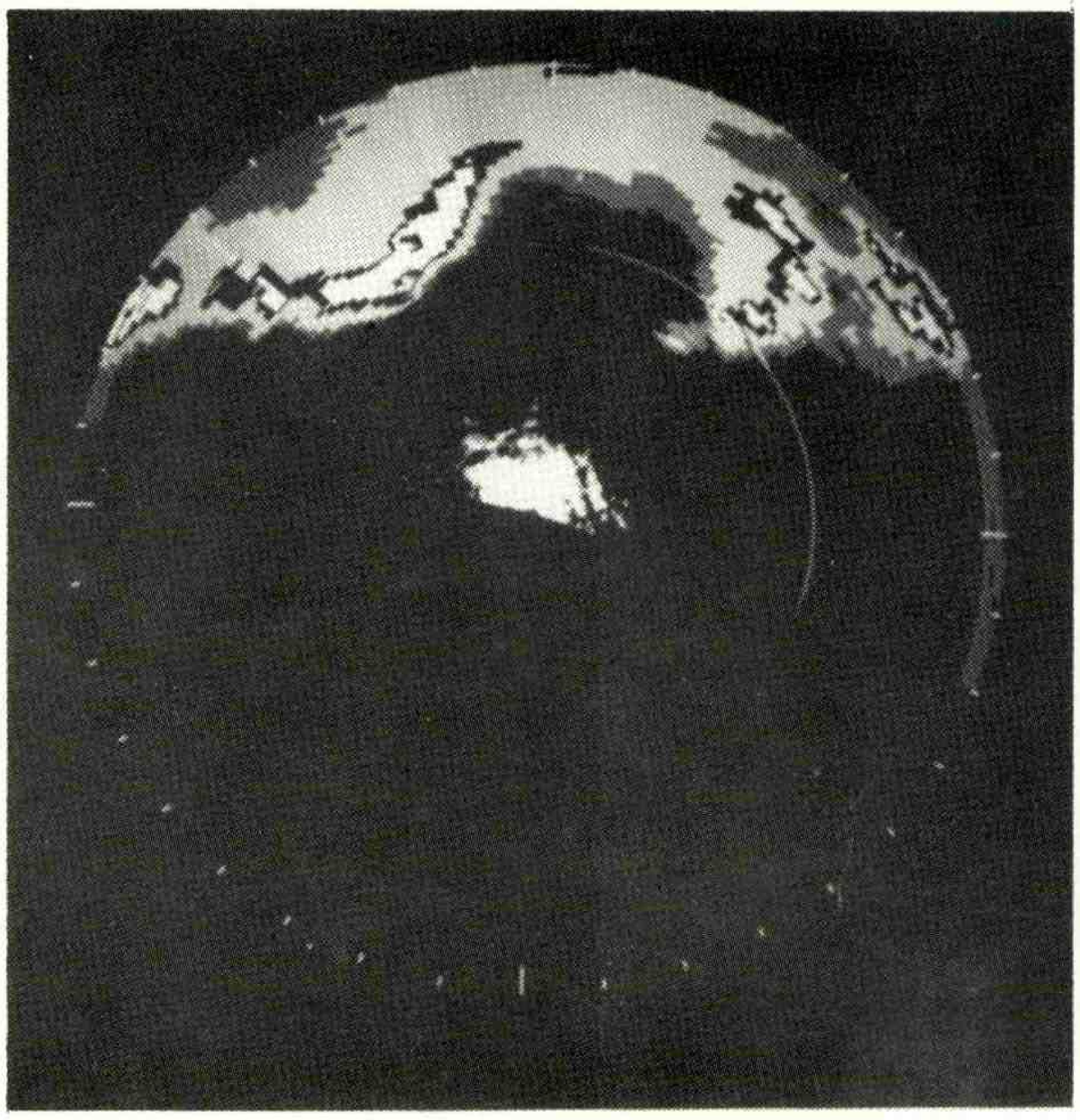


Figure 21. Remote radar display PPI, 200 km range, 2105 CST, June 6, 1975.

Figure 22. Remote radar display PPI, 200 km range, 2115 CST, June 6, 1975.

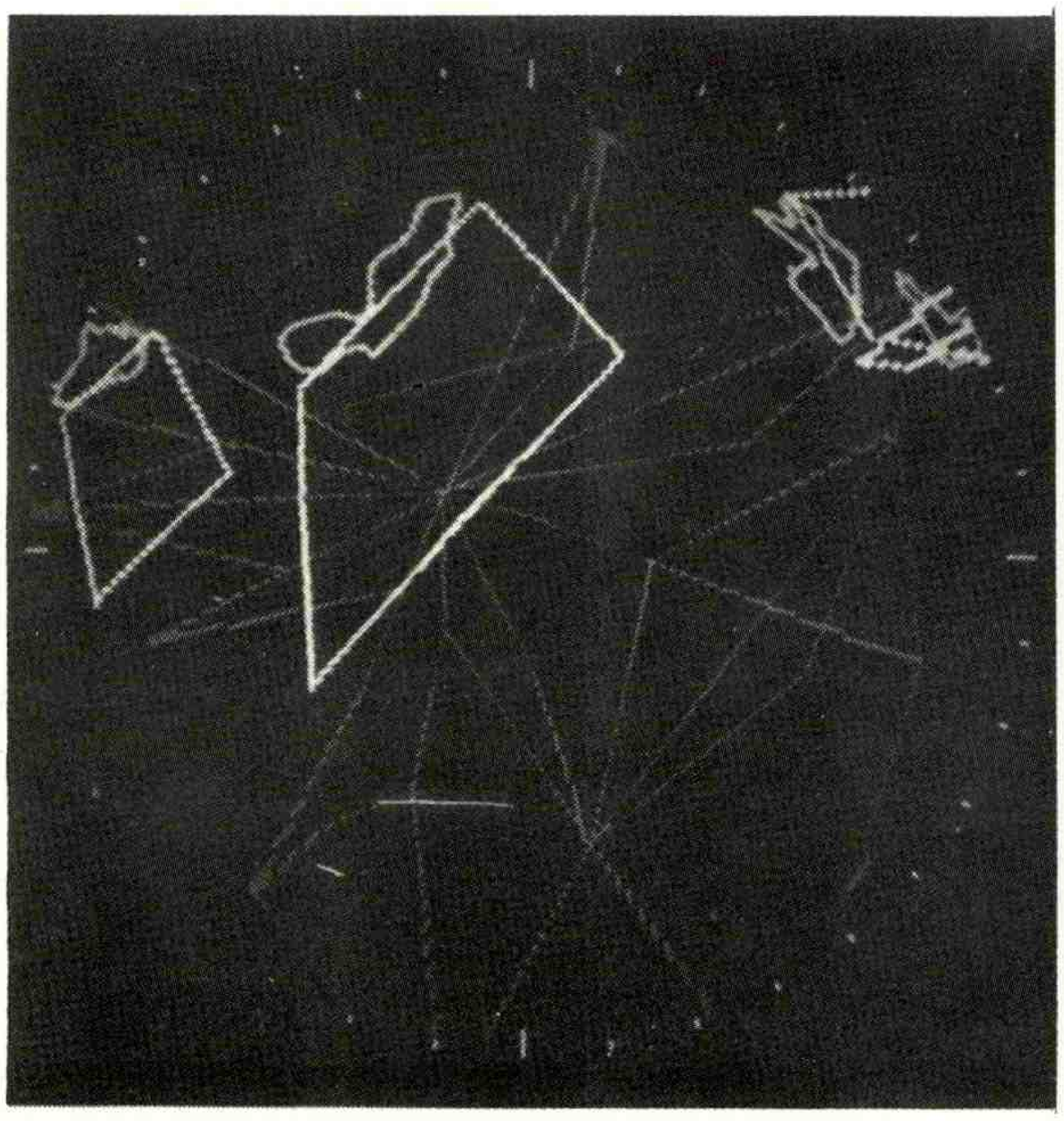


Figure 23. Remote radar display with computer generated warning areas, echo contours and Victor airways, June 6, 1975. Prediction period is 2130 to 2230 CST.

Figure 24. Remote radar display PPI, 200 km range, 2120 CST. June 6, 1975.

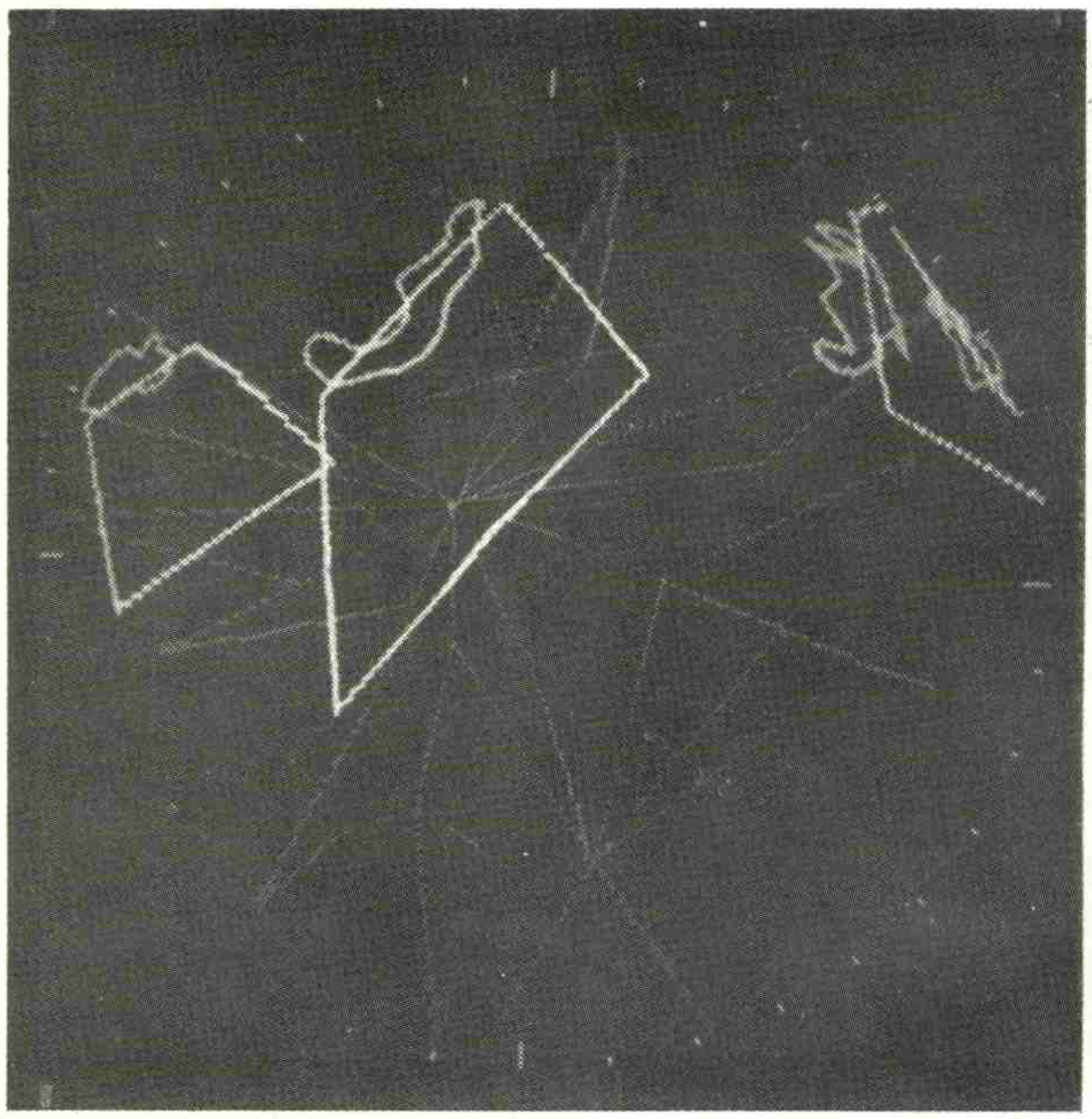


Figure 25. Remote radar display computer generated warning areas, echo contours and Victor airways, June 6, 1975. Prediction period is 2135 to 2235 CST.

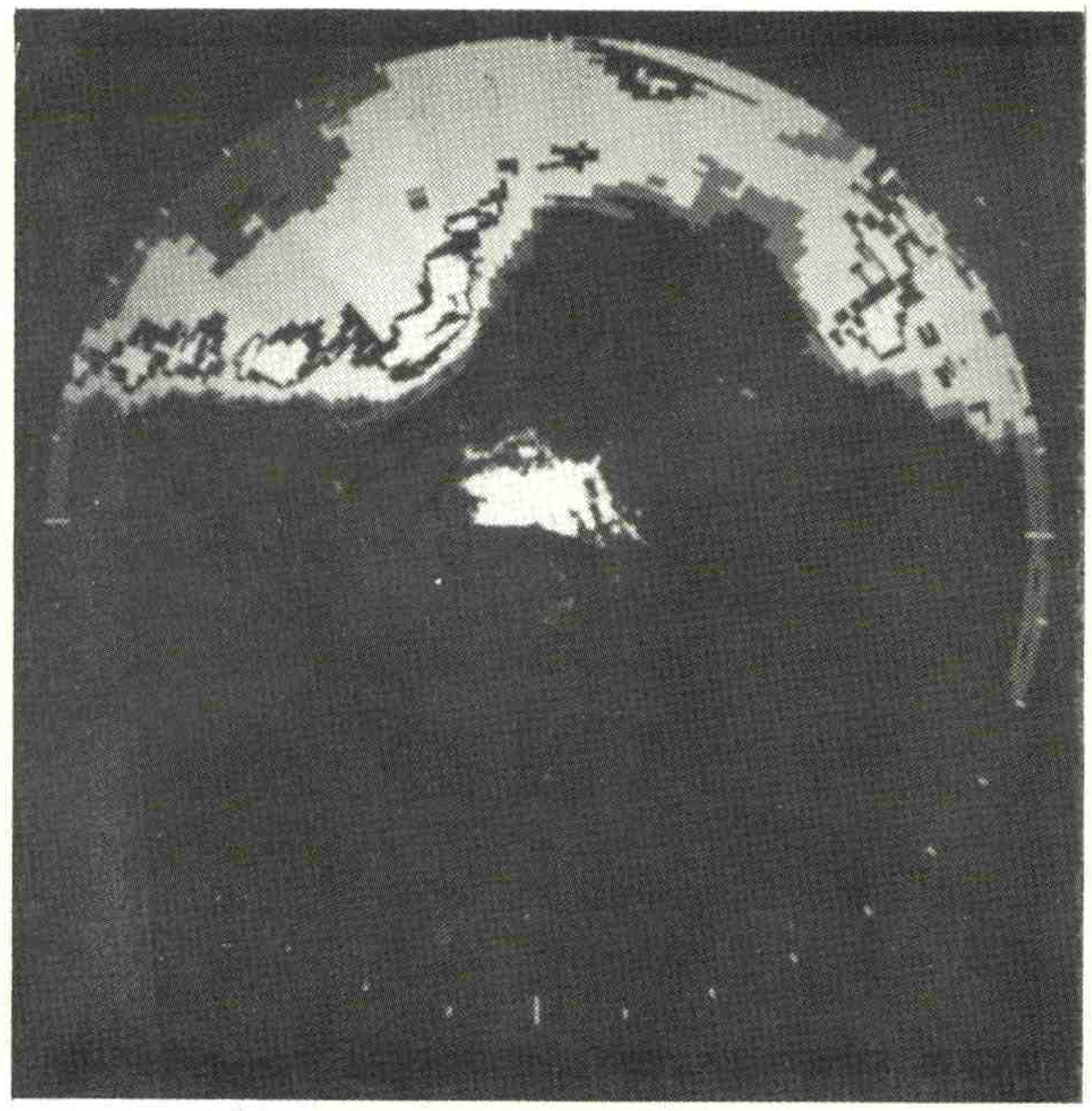


Figure 26. Remote radar display PPI, 200 km range, 2130 CST, June 6, 1975.

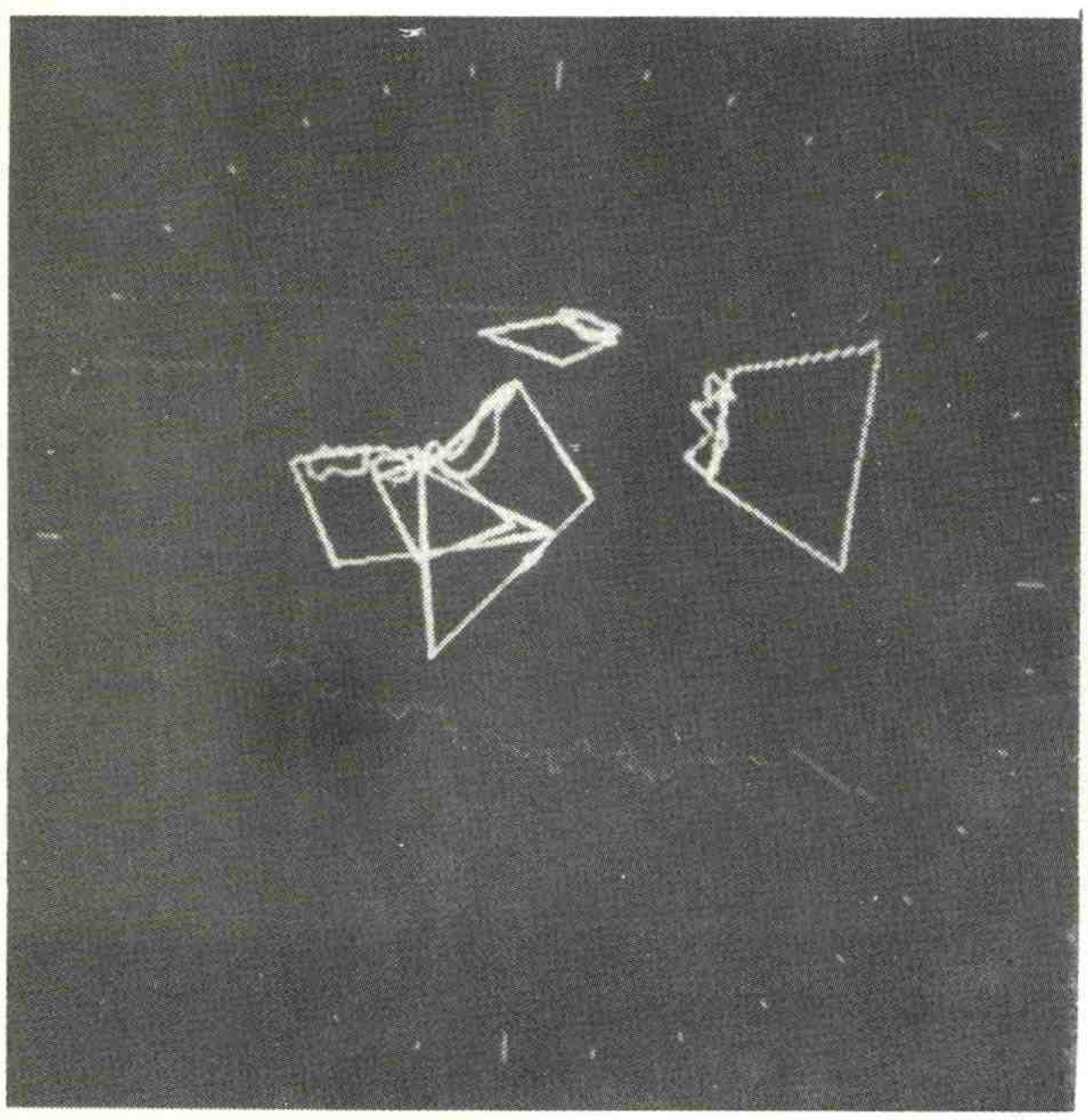


Figure 27. Remote radar display with computer generated warning areas, echo contours and Oklahoma State outline, 400 km range June 6, 1975. Prediction time is 2145 to 2245.

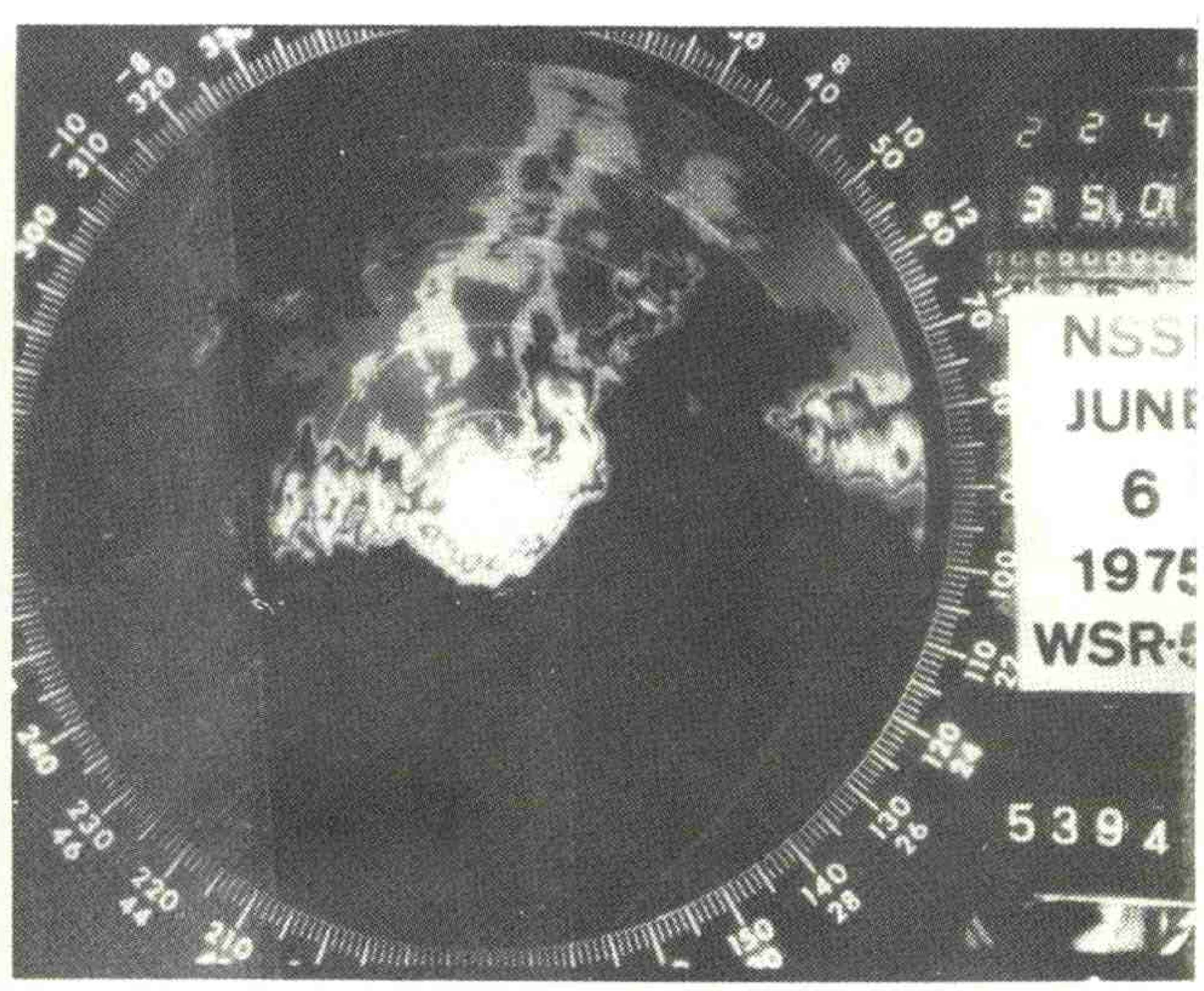


Figure 28. WSR-57 radar PPI, 200 km range, 40 km range marks, 2249 CST, June 6, 1975.

Case 2, June 16, 1975

On this day, moisture from the Gulf of Mexico and drier continental air were separated by a stationary surface front extending from the Oklahoma panhandle across southern Oklahoma and northern Arkansas (fig. 29). During the next 24 hours this boundary moved northeastward as a warm front ahead of a cold front approaching from the northwest.

The flow at 500 mb was essentially zonal at 20-30 kt (fig. 20). Mixing ratio values during the afternoon of the 16th were 16-18 g kg^{-1}, and the air mass was potentially unstable. When convective temperature was reached after 1500 CST, numerous showers and thunderstorms developed over Kansas, Oklahoma, north Texas and New Mexico. The sequence of satellite photographs and WSR-57 PPI displays (figs. 32a, b, c, and 33a, b, c) trace the growth and movement of these storms during the afternoon.

Until 1830 CST, activity was beyond 200 km, and the radar integrator was range delayed (fig. 32) to provide 1 km resolution data between 200 and 400 km (Sirmans and Doviak, 1973). After 1830 CST, data collection was normal with data recorded at five minute intervals.

The area of thunderstorms visible over northern Texas on the GOES satellite photos appeared as a line of moderate to intense echoes on the WSR-57 display. These storms intensified and moved rapidly across central Oklahoma as an organized squall line, preceded by a strong damaging gust front. The NSSFC issued a tornado watch at 1815 CST valid from 2000 CST to 0200 CST to cover western Oklahoma, but it lagged spatially behind the storms because of their unexpected acceleration. The steering level wind velocity was 210 degrees at 25 kts (46 km hr^{-1}). However, line motion was much faster from 270 degrees at 45 kts (80 km hr^{-1}). Figures 34 and 35, 30 minutes before tracking began, shows the storm influenced surface streamline and convergence patterns, respectively.

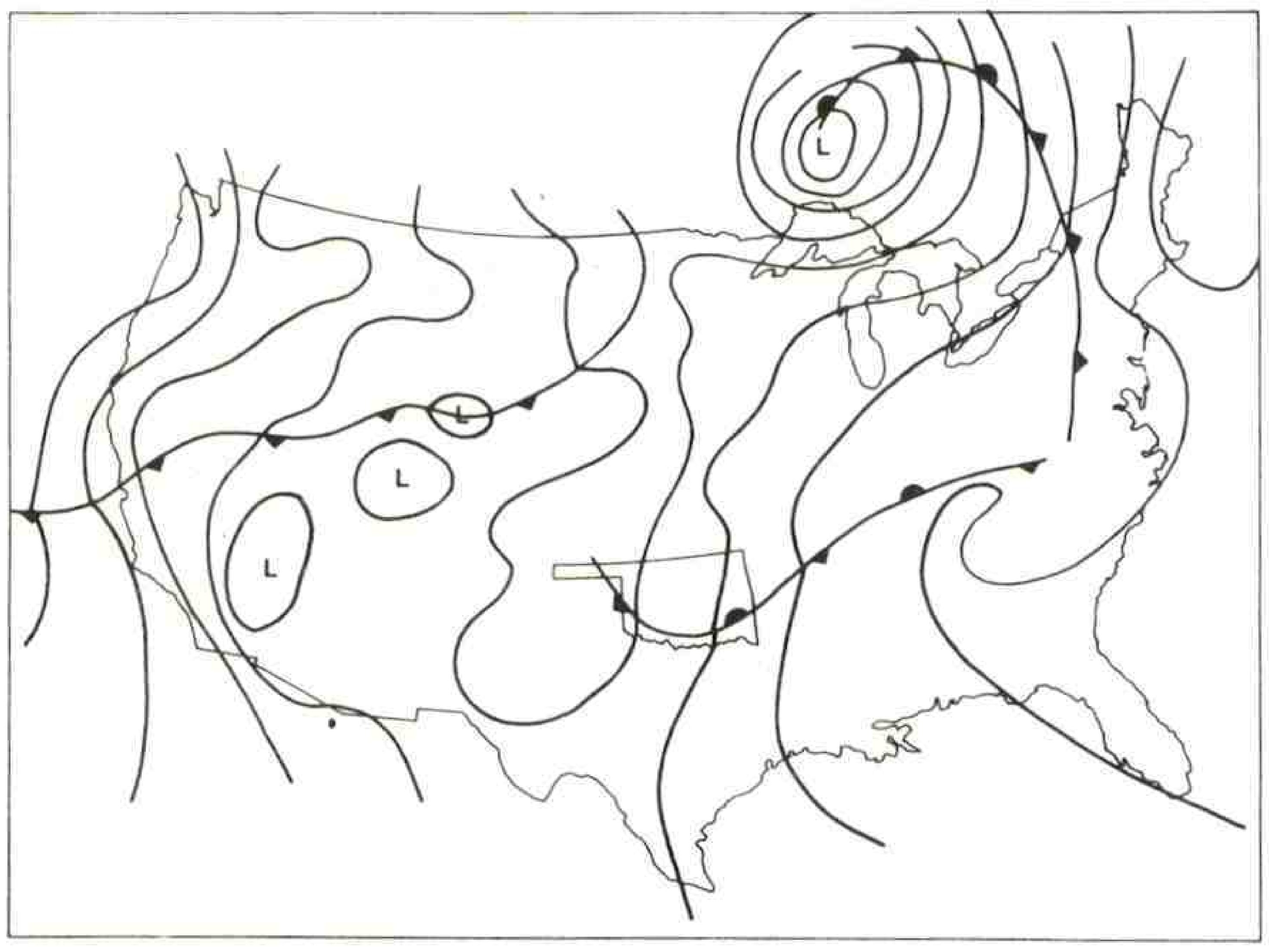


Figure 29. June 16, 1975, 12Z surface analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

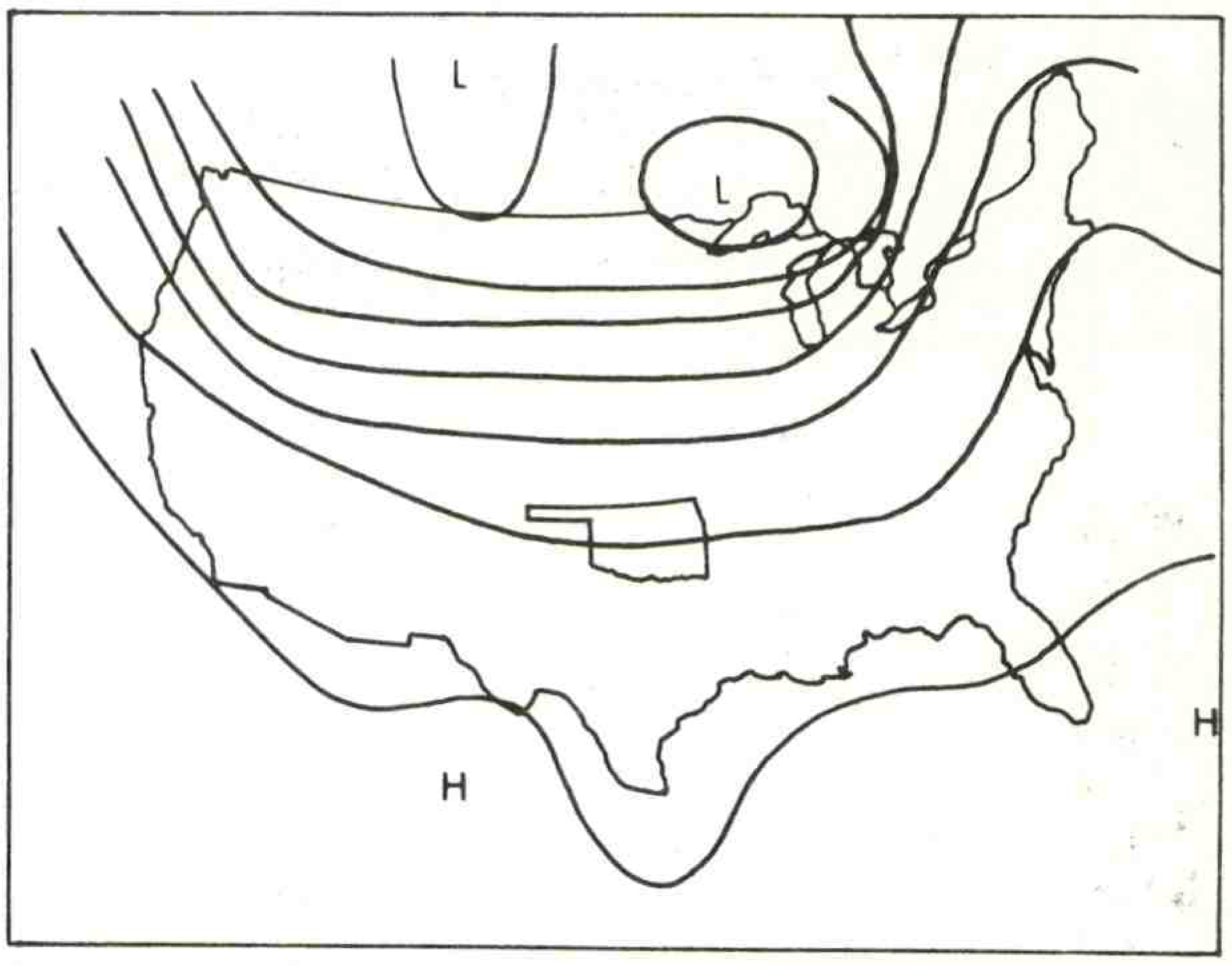


Figure 30. June 16, 1975, 12Z 500 mb analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

(a)

(b)

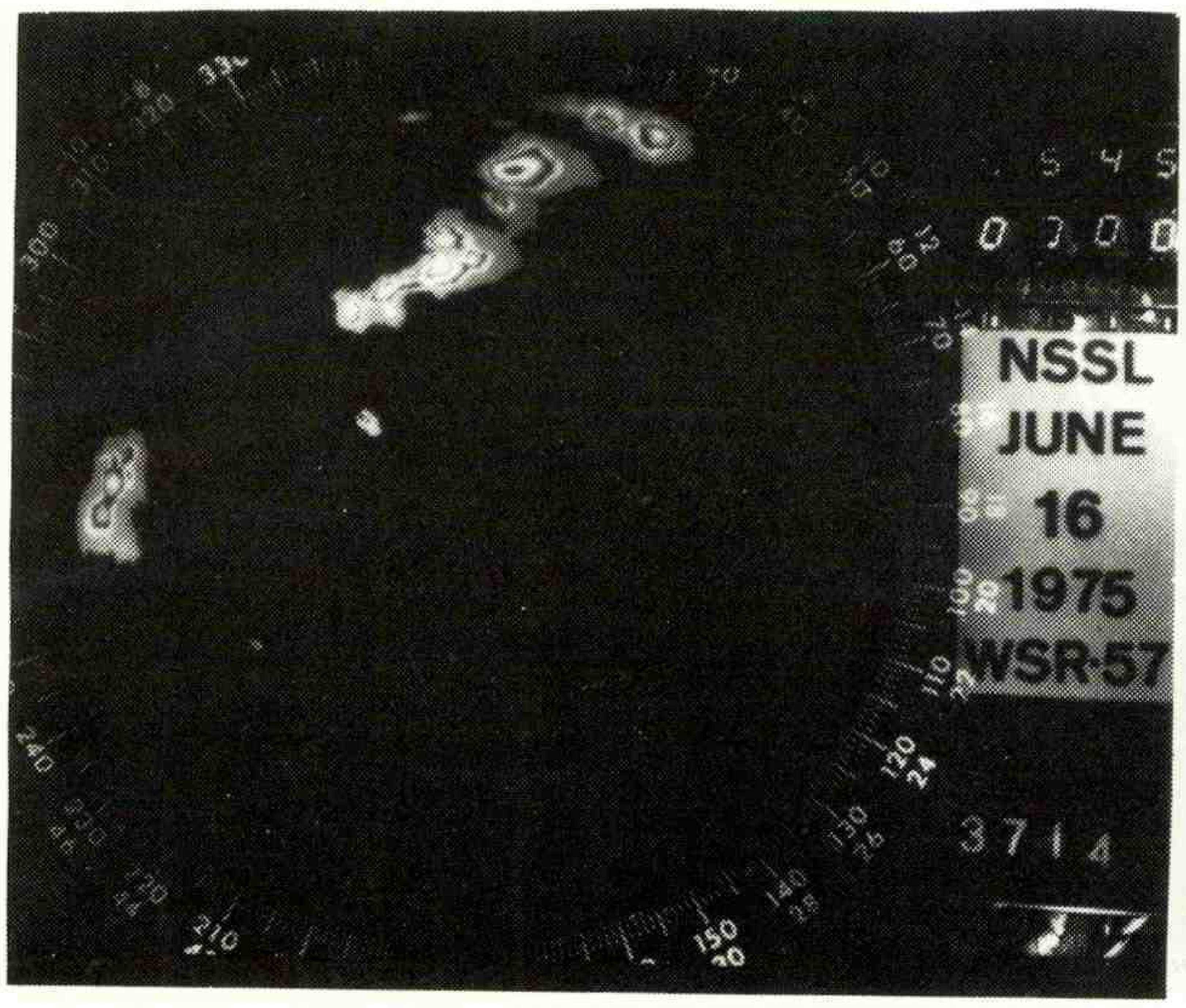
(c)

Figure 31. SMS-3 satellite pictures, June 16, 1975:

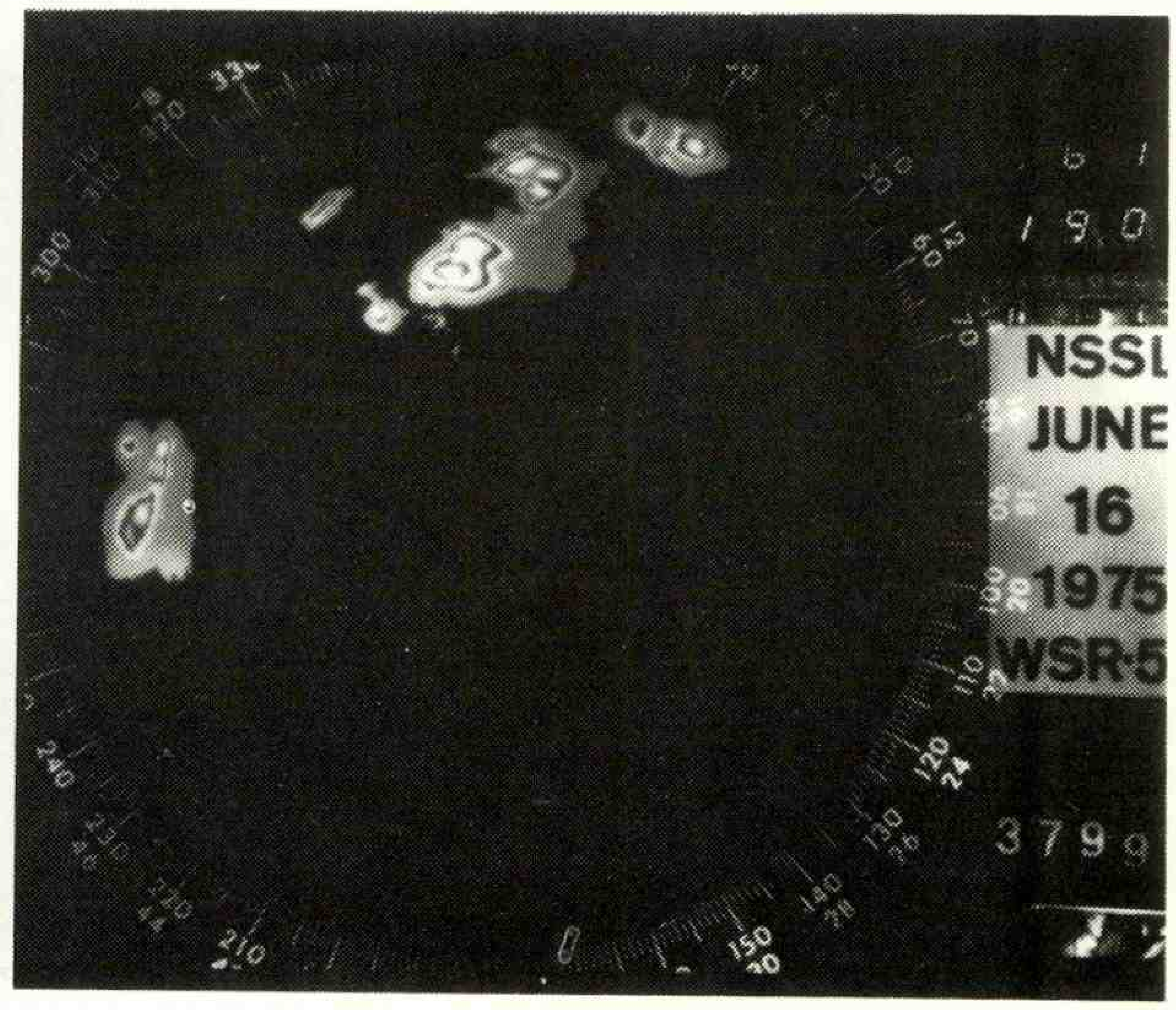
(a) 1545 CST (2145Z)

(b) 1615 CST (2215Z)

(c) 1745 CST (2345Z)



(a)



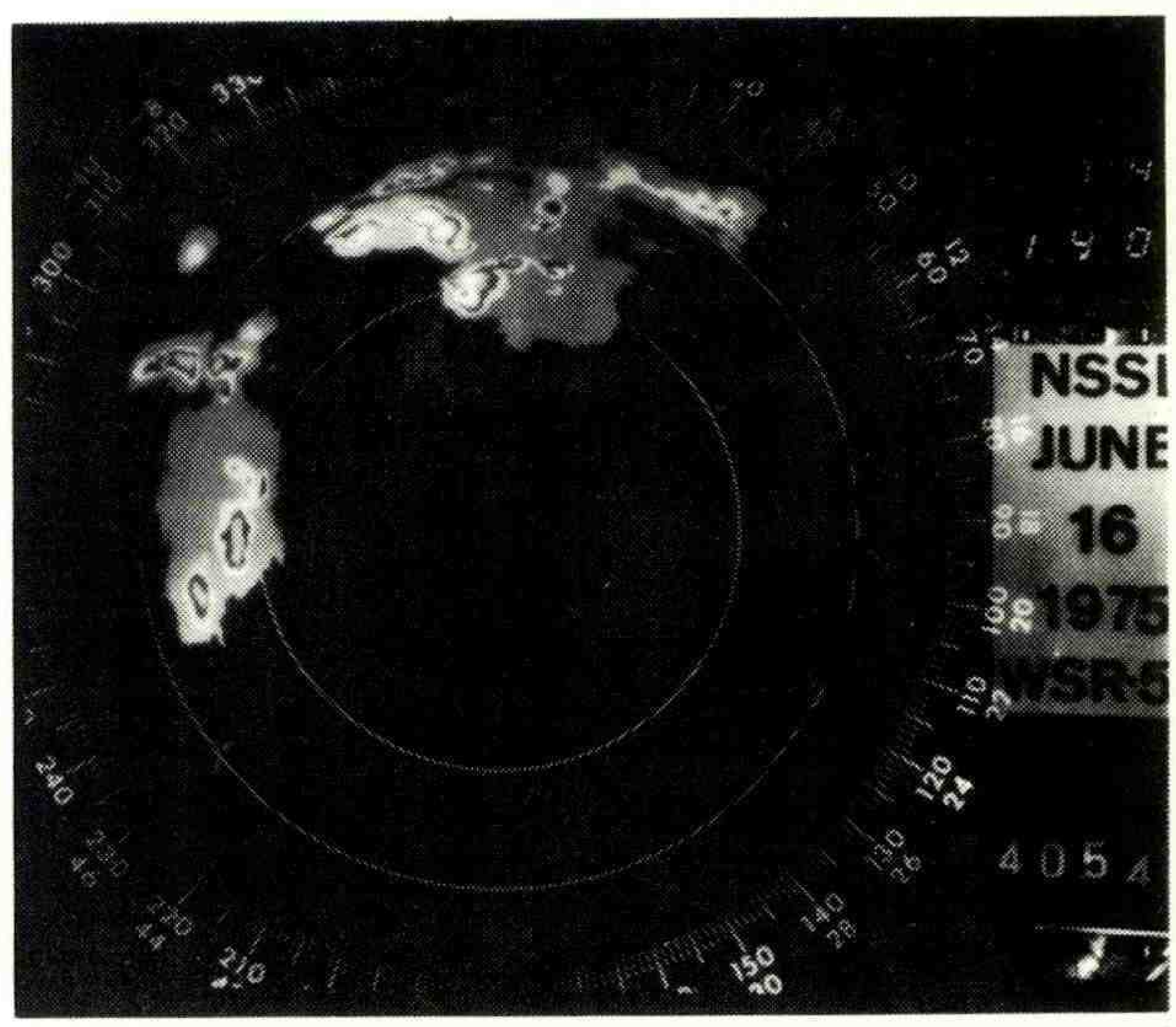
(b)

Figure 32. WSR-57 radar PPI, 400 km range with 200 km range delay to first gate, 40 km range marks, June 16, 1975:

(a) 1545 CST

(b) 1615 CST

(c) 1745 CST



(c)

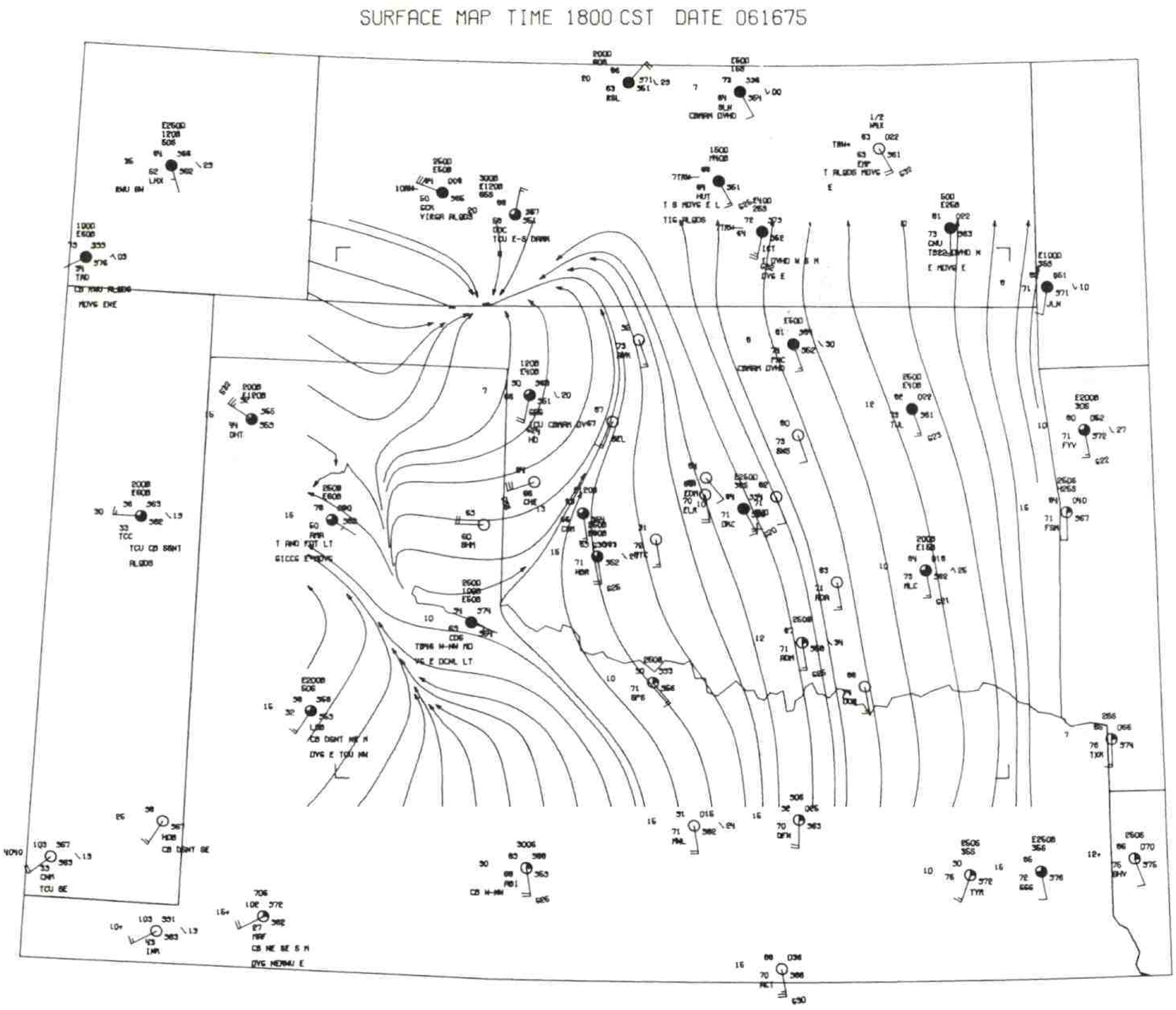


Figure 33. Subsynoptic surface data provided by NWS, FAA, and NSSL stations, 1800 CST, June 16, 1975, with streamlines superimposed.

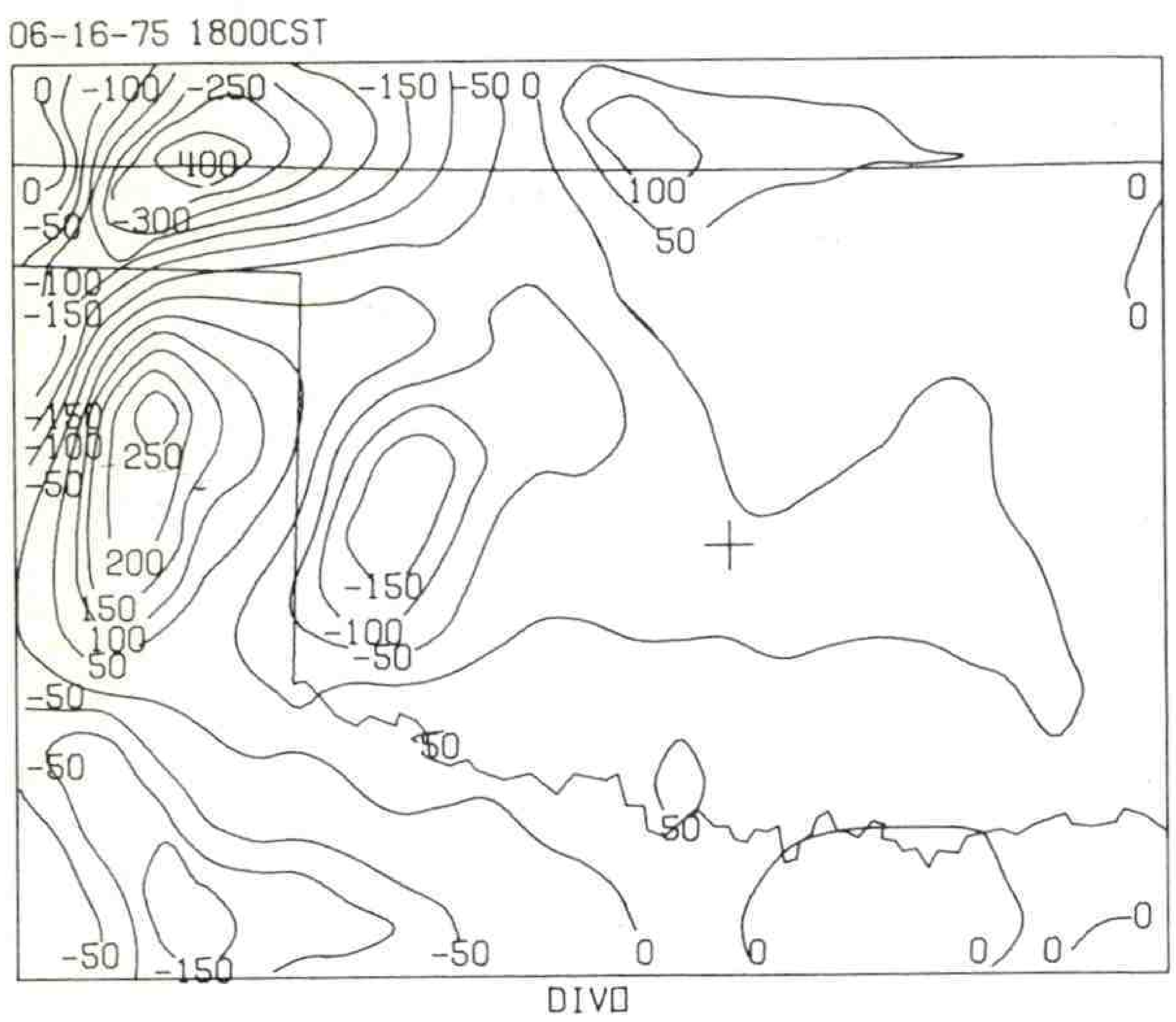


Figure 34. Divergence field derived from surface data, 1800 CST, June 16, 1975.

Testing of the echo prediction logic began with the 1830 CST observation. Using intensity and area thresholds of 40 dBZ and 250 km^2, respectively, the storm centroids were determined at 5 minute intervals. The four-level intensity code for the remote display was set to light, medium, cancel and bright (1220333). The time weight constant (TWC) was 2400, and the minimum range (GCD) was 20 km. All warning areas were for one hour interval starting with the time of the last observation.

After two PPI's (figs. 35 and 36) centroid positions for cell 1 were entered and an estimate of the echo's motion (from 337 degrees at 44 km hr^{-1}) was obtained (Table 3). Figure 37 shows the subsequent warning area based on two centroid positions.

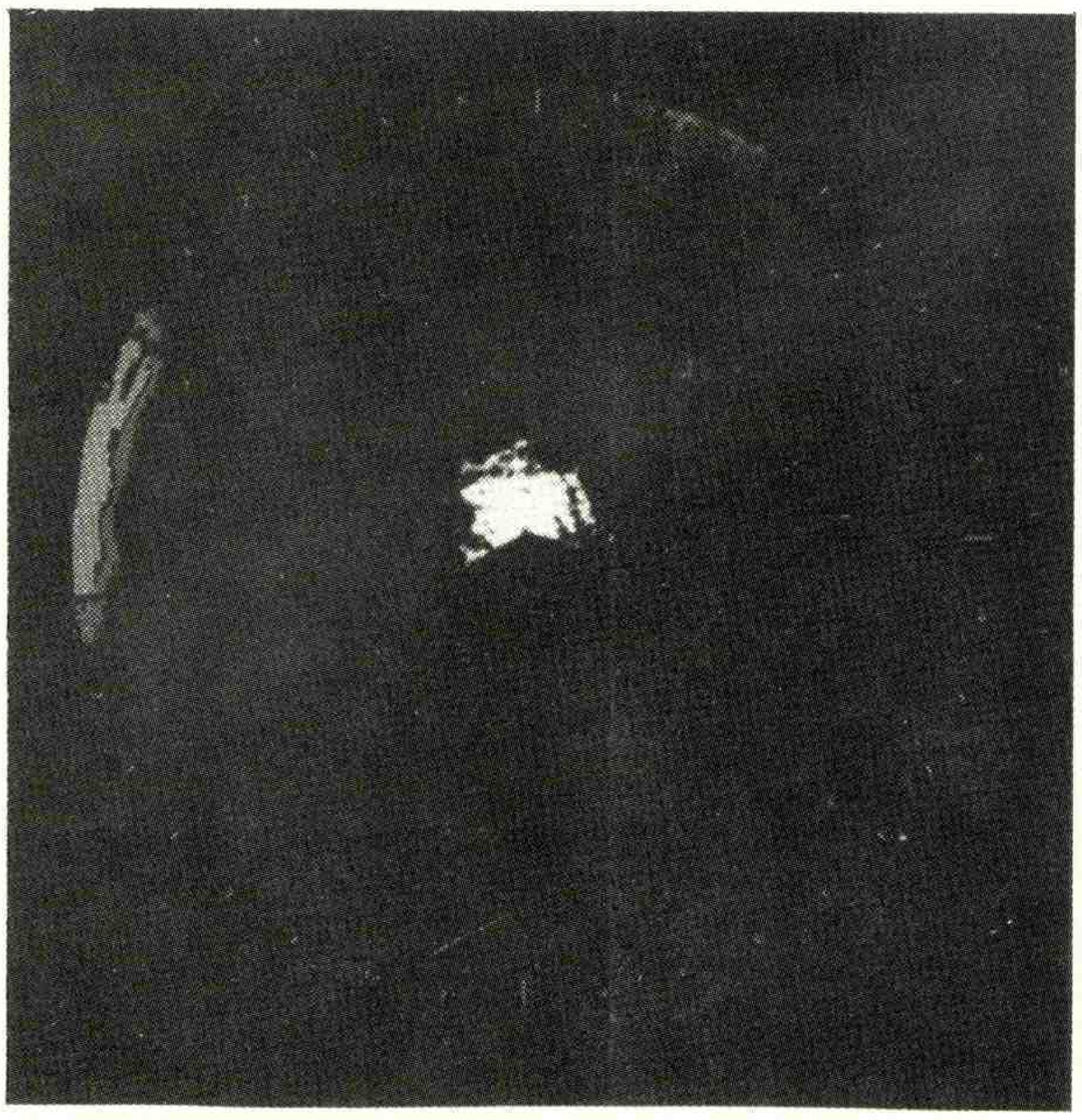


Figure 35. Remote radar display PPI, 200 km range, 1830 CST, June 16, 1975.

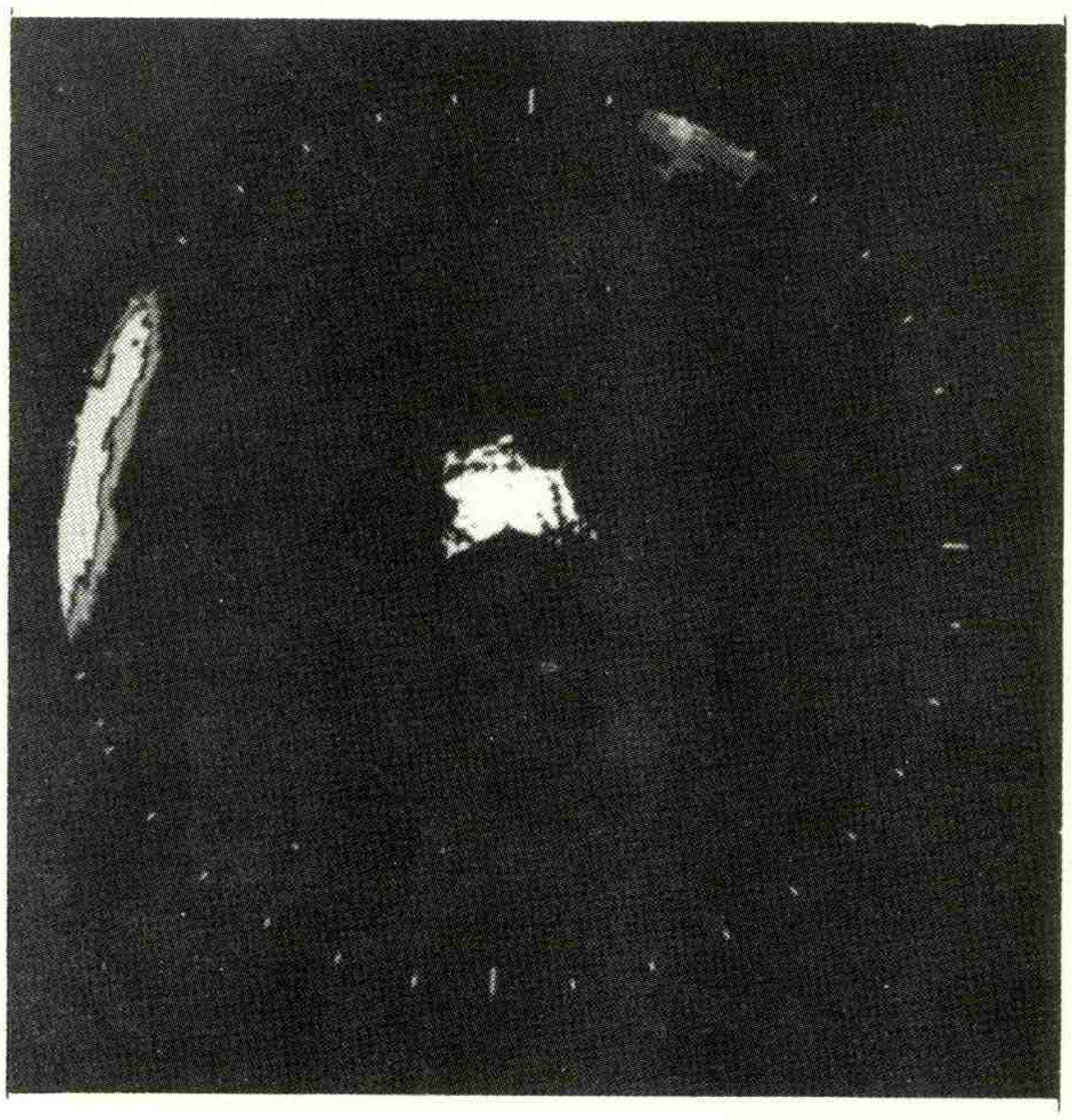


Figure 36. Remote radar display PPI, 200 km range, 1835 CST, June 16, 1975.

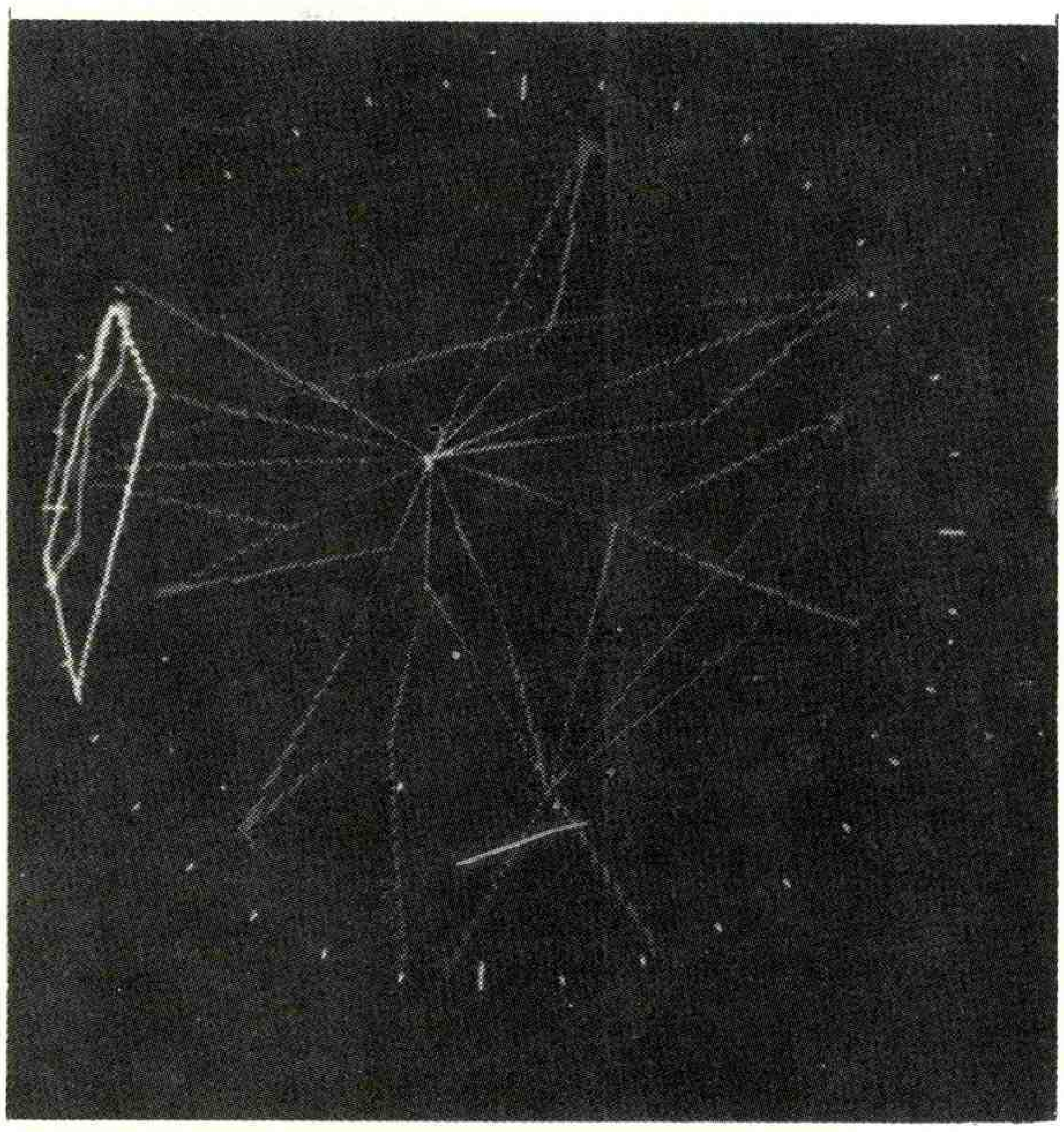


Figure 37. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 1835 to 1935 CST.

It is important to note here that as an echo enters the scope, its centroid position will be influenced by the area change. As a result, using centroid positions to calculate echo motion will underestimate true echo speed. Likewise, direction of motion will be affected. If the increase in each area occurs only at one end of a line, the calculated direction of motion will be pulled towards that end. Until such time as an echo or squall line has fully entered the scope, it is probably better to track a point along its leading edge. (That was not done for this case.)

From Table 3, an increase in line speed is evident through the first half hour of tracking. Because of the boundary problem just described, large values of σ_t and σ_d resulted. An example of a PPI and its associated warning area at 1900 CST are shown in Figures 38 and 39.

Table 3. Echo centroid positions, direction and speed predicted, and the RMSE values for June 16, 1975.

ECHO NO.	TIME (CST)	AZIMUTH (DEGREES)	RANGE (KM)	DIRECTION (DEGREES)	SPEED (KM HR^{-1})	σ_d (KM)	σ_t (HOUR)
1	1830	280.	188.	-	-	-	-
1	1835	279.	186.	338.0	45.9	-	-
1	1840	278.	183.	331.3	49.3	6.59	0.070
1	1845	279.	179.	302.5	39.2	31.11	0.516
1	1850	276.	174.	314.0	52.1	43.65	0.843
1	1855	273.	171.	324.0	63.3	46.94	0.845
1	1900	271.	165.	325.4	71.5	43.74	0.812
2	1905	262.	170.	-	-	-	-
3	1905	287.	151.	-	-	-	-
2	1910	261.	167.	305.9	55.2	-	-
3	1910	285.	142.	315.6	135.9	-	-
2	1915	261.	159.	276.1	69.7	39.15	0.134
3	1915	287.	133.	287.0	110.4	59.72	0.299
1	1920	264.	146.	321.3	77.7	41.41	0.761
1	1925	263.	140.	318.7	78.4	41.81	0.720
1	1930	263.	132.	315.3	77.8	46.93	0.690
1	1935	260.	126.	313.3	78.7	44.85	0.668
1	1940	258.	120.	311.7	79.3	43.72	0.640
1	1945	259.	111.	309.0	79.1	50.48	0.626
4	1950	263.	110.	-	-	-	-
4	1955	264.	108.	219.9	36.2	-	-
4	2000	267.	97.	235.9	91.2	28.38	1.627
5	2005	263.	82.	-	-	-	-
5	2010	263.	74.	263.0	105.0	-	-
5	2015	263.	64.	263.0	110.4	0.01	0.082
6	2020	285.	51.	-	-	-	-
6	2025	284.	46.	294.1	66.6	-	-
6	2030	287.	41.	276.9	62.1	20.79	0.099

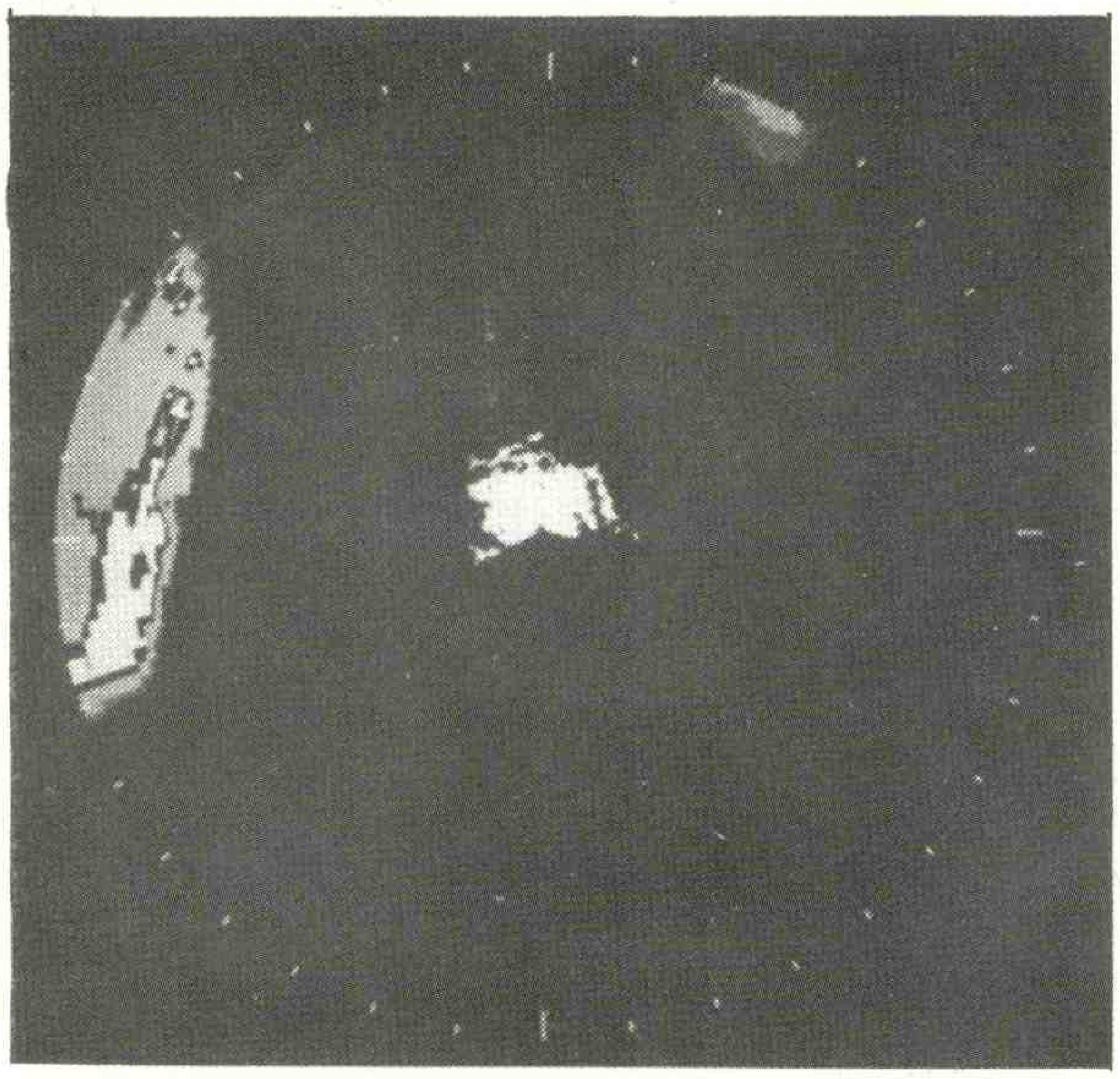


Figure 38. Remote radar display PPI, 200 km range, 1900 CST, June 16, 1975.

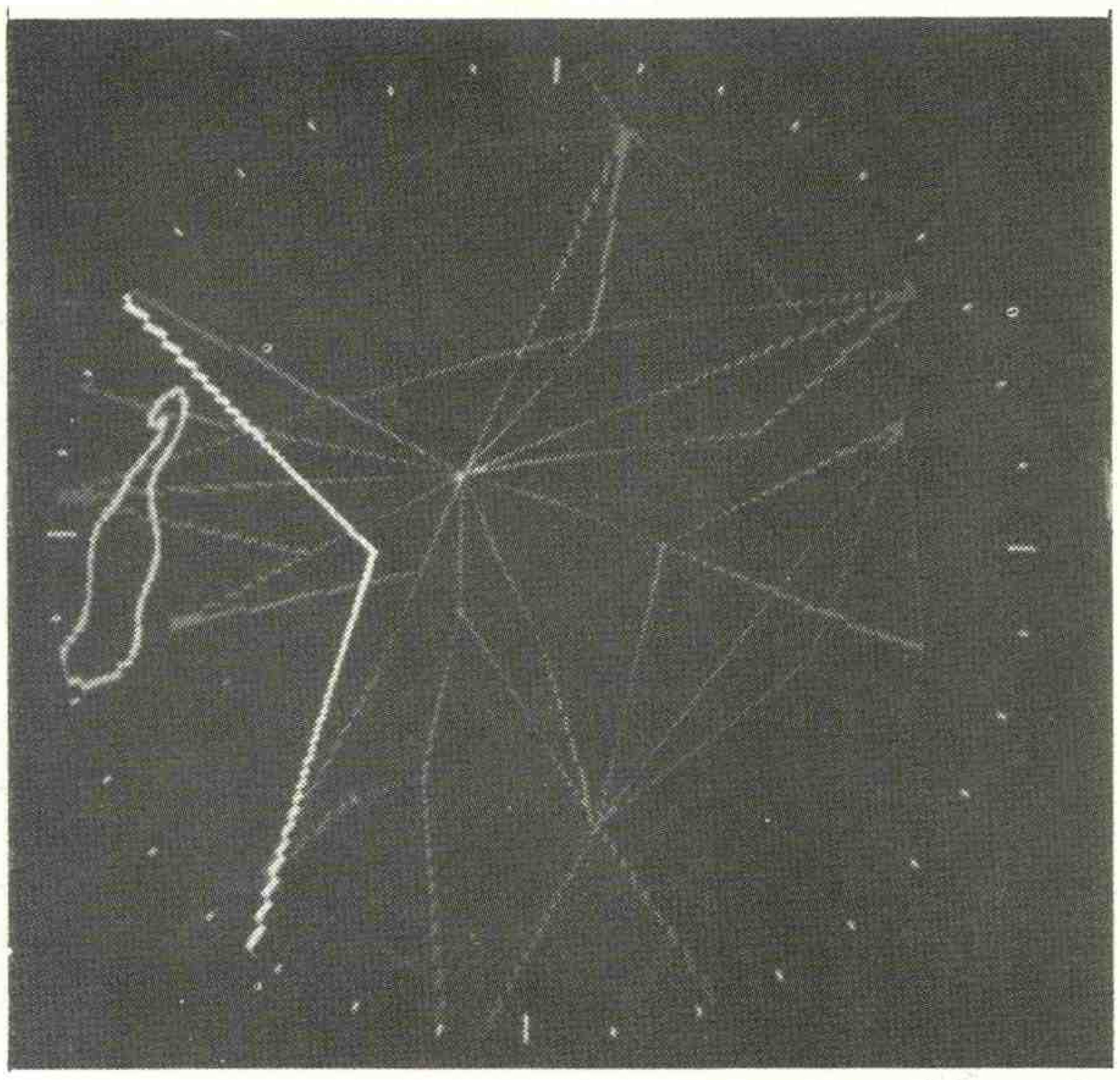


Figure 39. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 1900 to 2000 CST.

At 1905 CST, the program logic isolated two discrete cells within the line at intensity 40 dBZ where there had been only one five minutes before. The split-off of the smaller of the two cells caused the centroid of the larger cell to be shifted nine degrees in azimuth and moved back 5 km. After the split, the two cells were identified as cell 2 and cell 3 and tracked for the next ten minutes. The PPI at 1915 CST (fig. 40) and the graphics for that time (fig. 41) indicate quite different speeds for each cell (see also Table 3).

At 1920 CST, cells 2 and 3 merged. Since the resulting centroid position was consistent with the extrapolated position for cell 1, the merge was reassigned as cell 1 (fig. 42). It was traced until 1945 CST. Two radar PPIs and their respective warning areas (figs. 43-46, at 1930 and 1945 CST) show the line's movement during this period.

After 1945 CST, in the initial pass through the data, the large core which had been cell 1, fragmented and attempts to match the new cells proved futile. Therefore, a second pass was made with new threshold criteria of 1000 km^2 and intensity level 3. The gray shading was recoded at 1203333 to reflect the decrease in the intensity threshold.

Cell 4, tracked from 1950 to 2000 CST, indicated motion in a northeasterly direction due, primarily, to growth on the north end of the line. Motion had been southeasterly previously. Shown in Figures 47 and 48 is a radar PPI and graphic warning for 2000 CST.

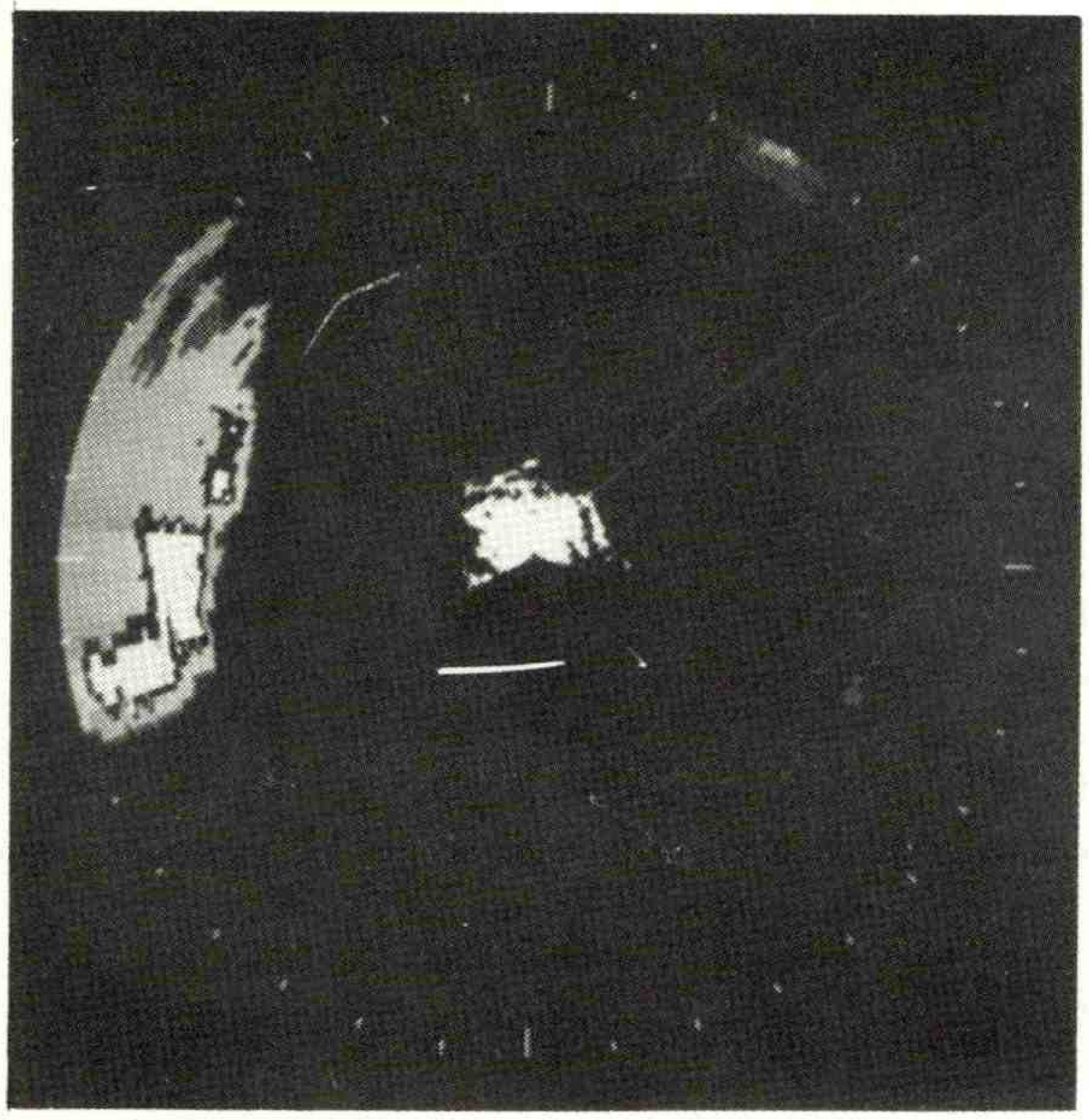


Figure 40. Remote radar display PPI, 200 km range, 1915 CST, June 16, 1975.

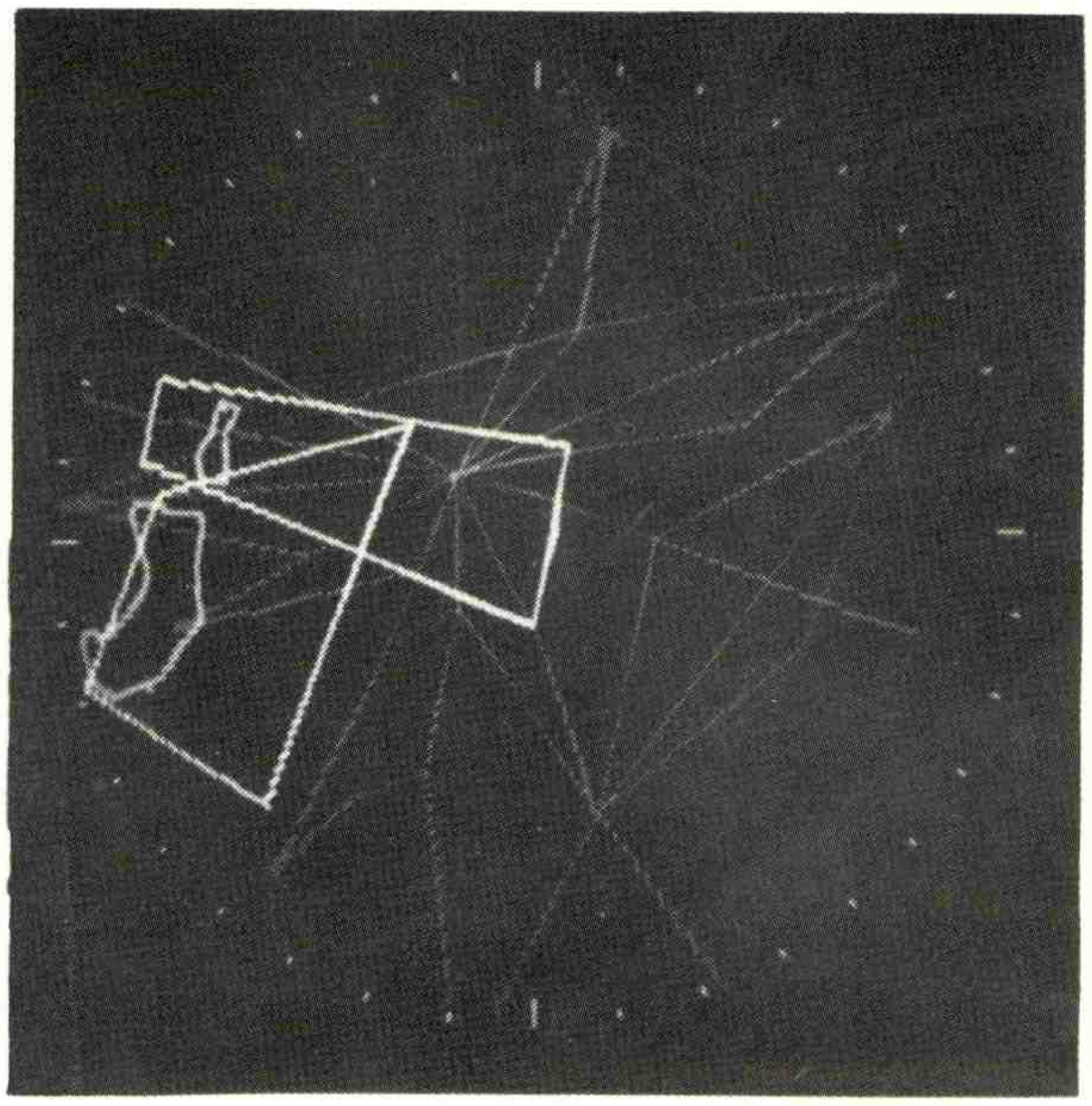


Figure 41. Remote radar display with computer generated warning areas, echo contours and Victor airways, June 16, 1975. Prediction period is 1915 to 2015 CST.

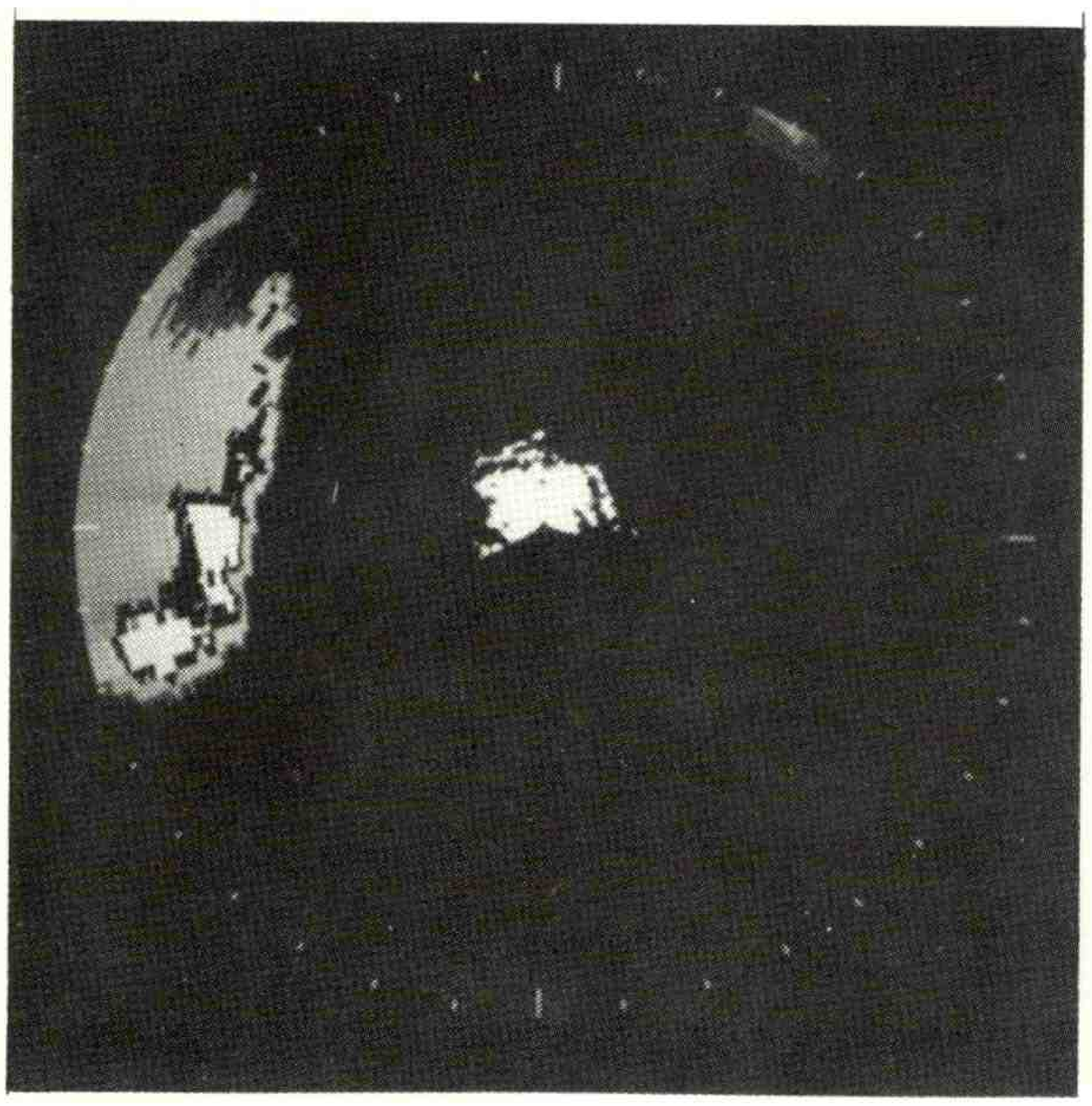


Figure 42. Remote radar display PPI, 200 km range, 1920 CST, June 16, 1975.

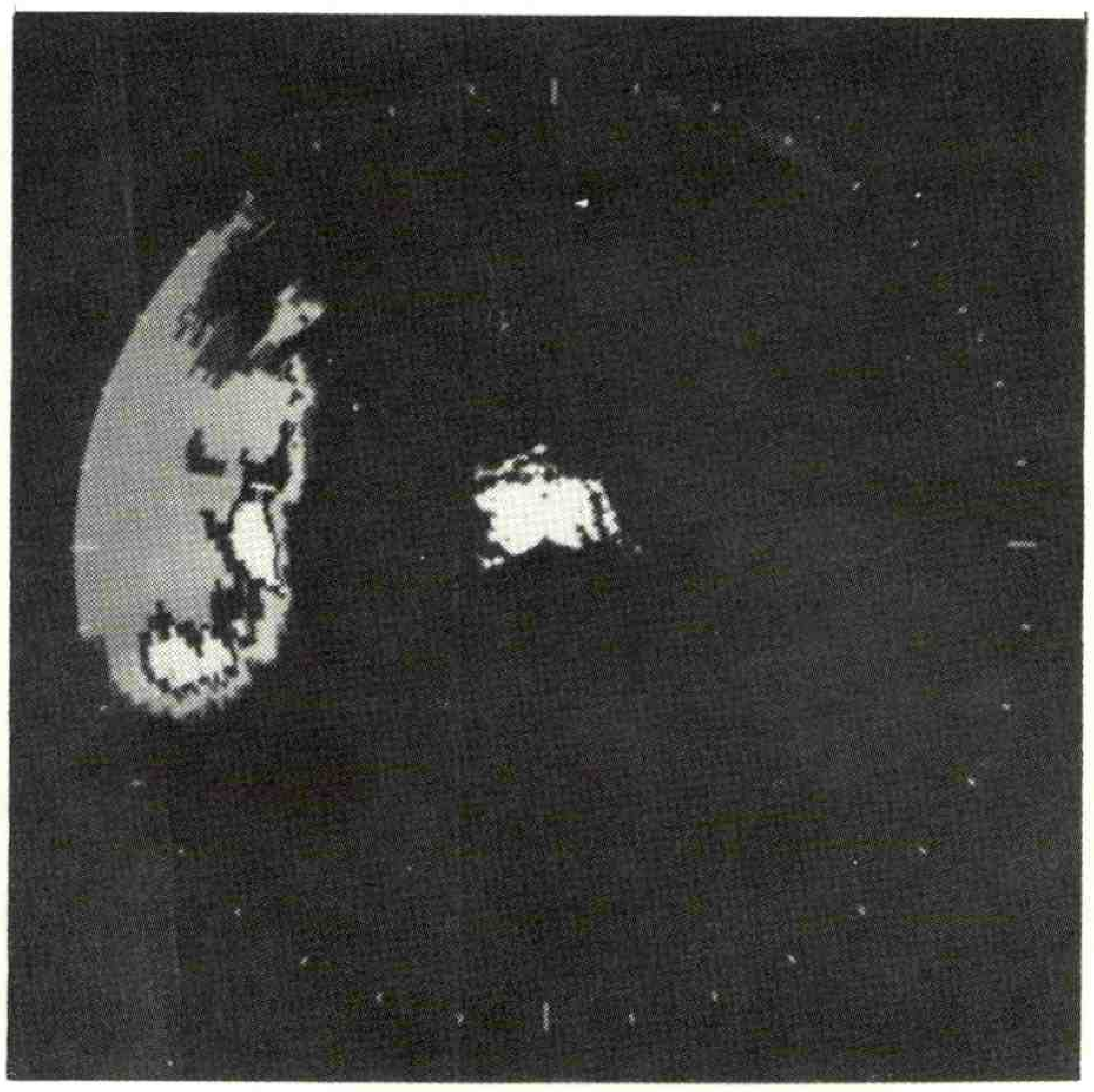


Figure 43. Remote radar display PPI, 200 km range, 1930 CST, June 16, 1975.

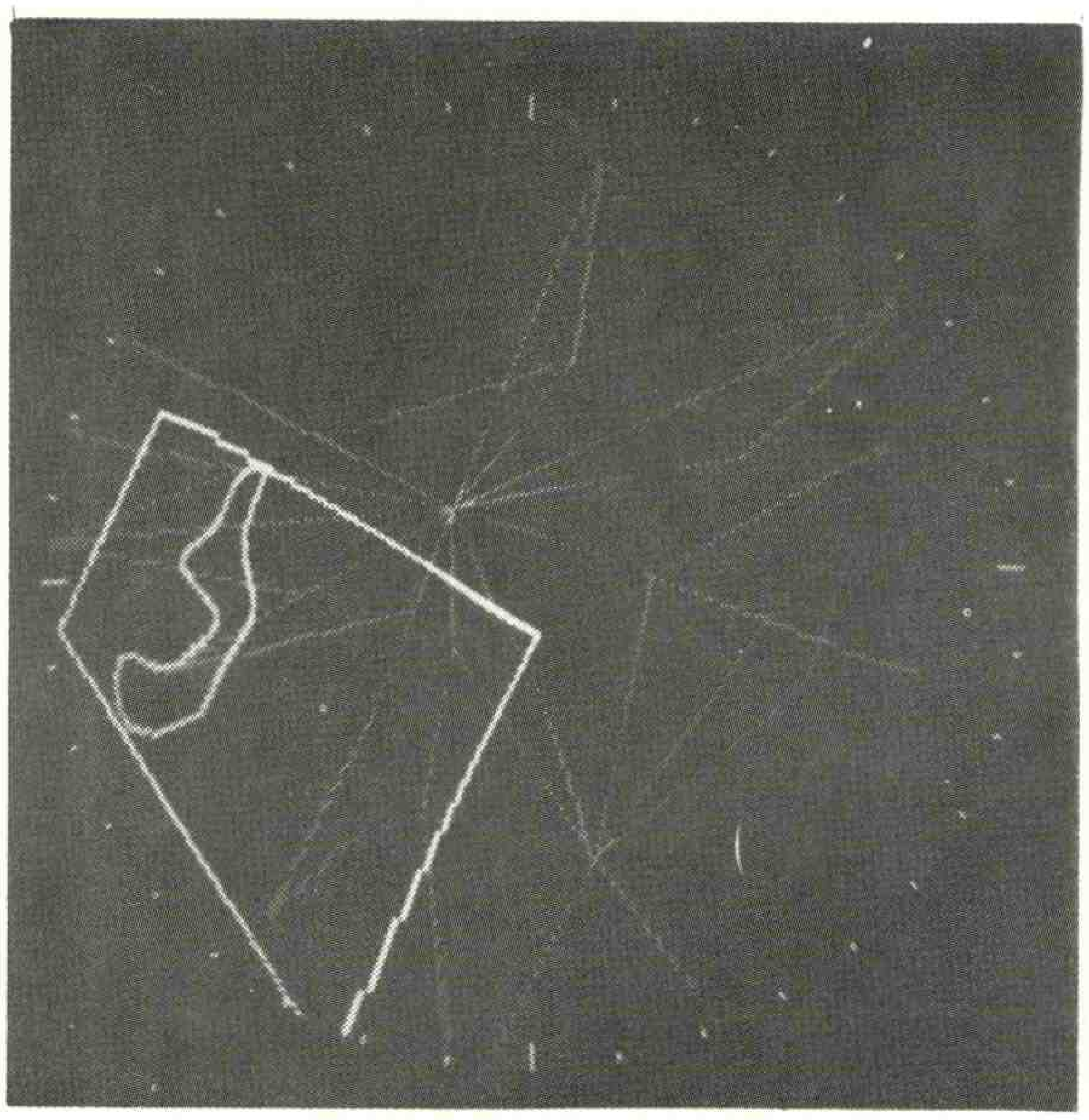


Figure 44. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 1930 to 2030 CST.

Figure 45. Remote radar display PPI, 200 km range, 1945 CST, June 16, 1975.

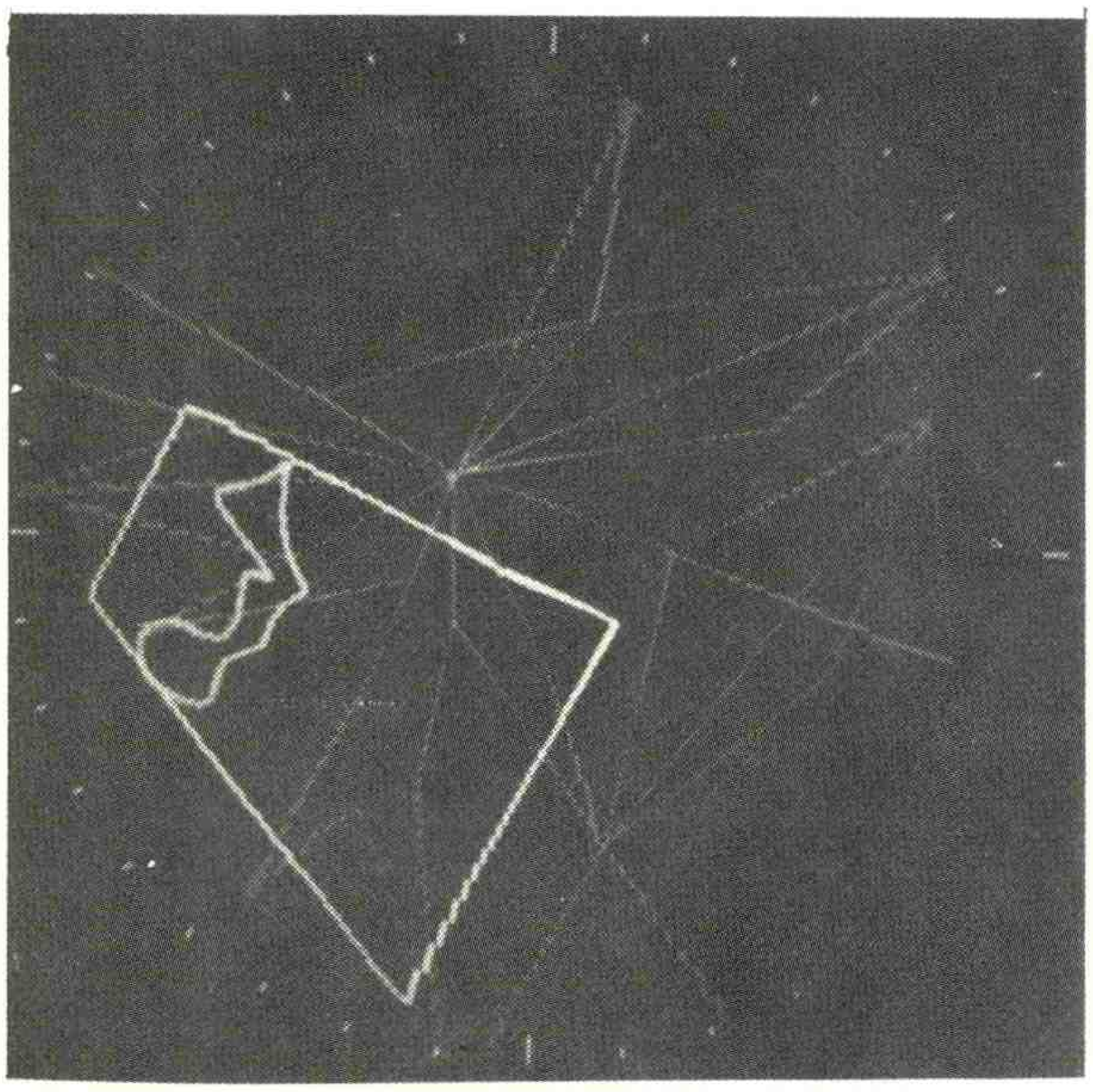


Figure 46. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 1945 to 2045 CST.

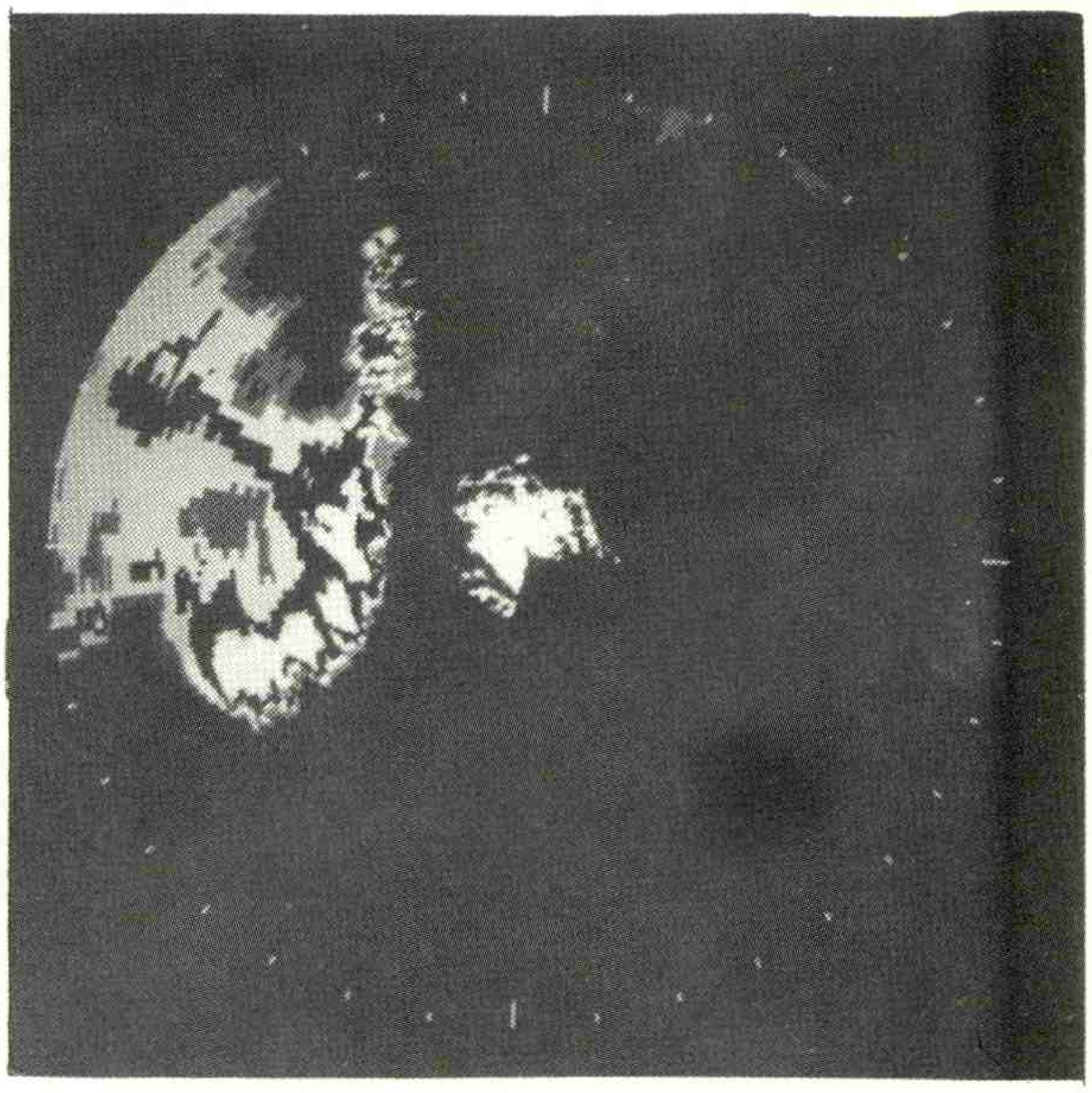


Figure 47. Remote radar display PPI, 200 km range, 2000 CST, June 16, 1975.

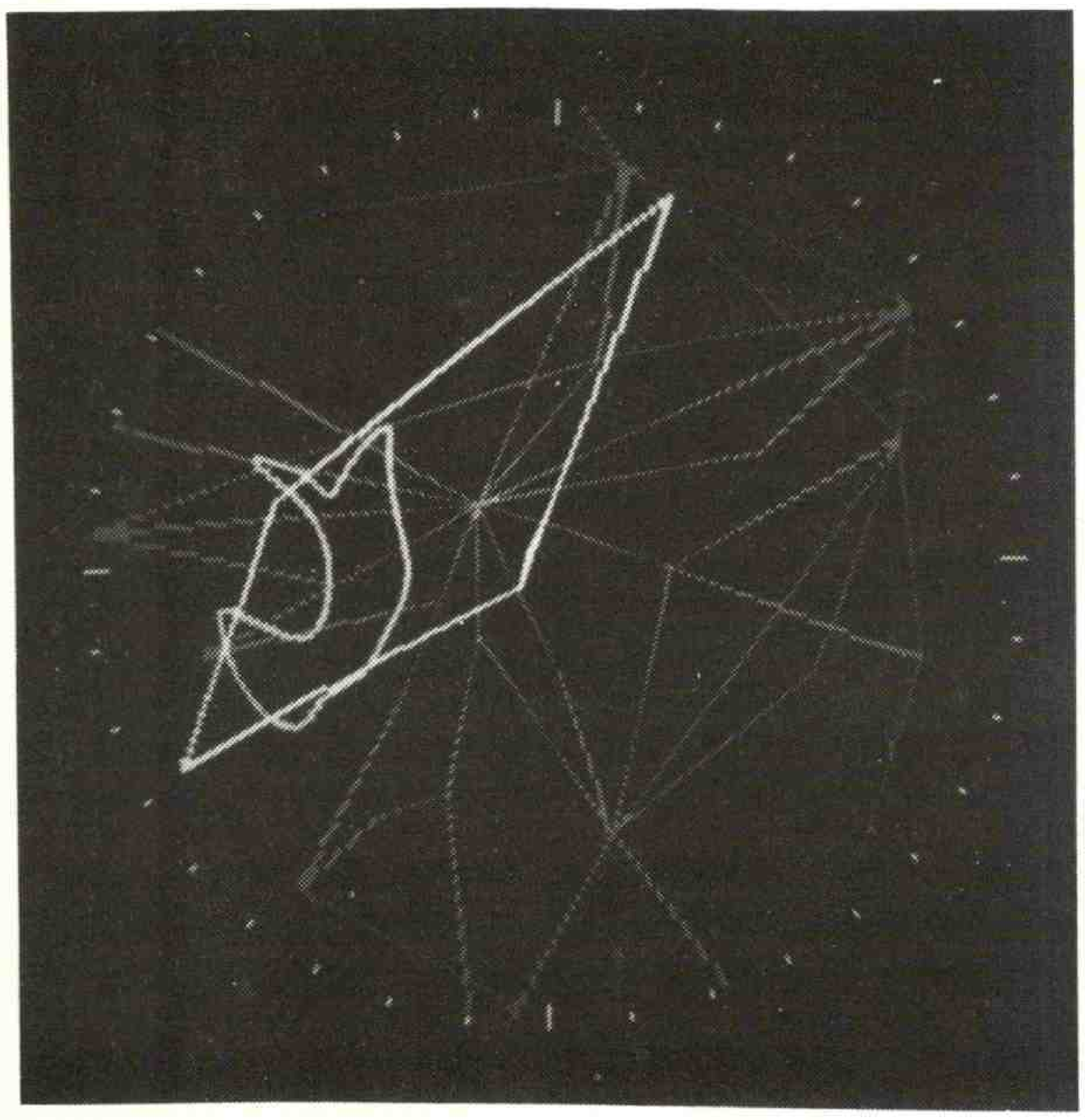


Figure 48. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 2000 to 2100 CST.

At 2005 CST, due to a substantial change in area and range, the largest echo was relabeled as cell 5. Like cell 4, cell 5 was also tracked for only 15 minutes. As shown in Figures 49 and 50, and Table 3, the warning area and echo motion after 10 minutes reflect the line's overall speed and direction of motion better than any earlier time.

A substantial change in area and centroid position again occurred about 2020 CST with the additional growth on the north end of the line. Cell 5 was dropped. The larger echo, renumbered as cell 6, moved slower, although the direction was the same. The PPI and warning area (fig. 51 and 52) are shown for 2030 CST when tracking ceased.

Probably a longer sampling interval should have been used for this case (e.g., 15 minutes). However, several factors have to be considered. The optimum sampling interval determined by Wilk and Gray (1970) was 45 minutes. Obviously, one can't wait that long before making a prediction. Also, the lifetime of the storm may be less than an hour. Conversely, if one samples too frequently, lack of spatial and temporal resolution will produce fictitiously large errors.

Another dilemma arises when matching echo manually. The more frequently one samples, the easier it is to follow echo motion and to account for splits and merges. (On some occasions it was difficult to match five minute data.) However, an unwarranted amount of time may be spent tracking small cells of short duration which neither produce severe weather nor have sufficient predictability to provide meaningful extrapolations.

Case 3, November 2, 1974

The storms developed early in the morning of November 2. On the previous day a stationary front extended across southern Texas and northern Louisiana (fig. 53). During the day, it evolved into a warm front which moved into southern Oklahoma (fig. 54). The position of the front changed little during the afternoon and evening of November 2 (fig. 55) as an upper level low developed over California, and maintained a stationary pattern of southwesterly flow aloft over Oklahoma.

At 500 mb (fig. 56) a broad trough covered most of the United States with two low pressure centers, one centered over northeast Wyoming, the other over northern California and Nevada. Between November 1 and 3 the northern

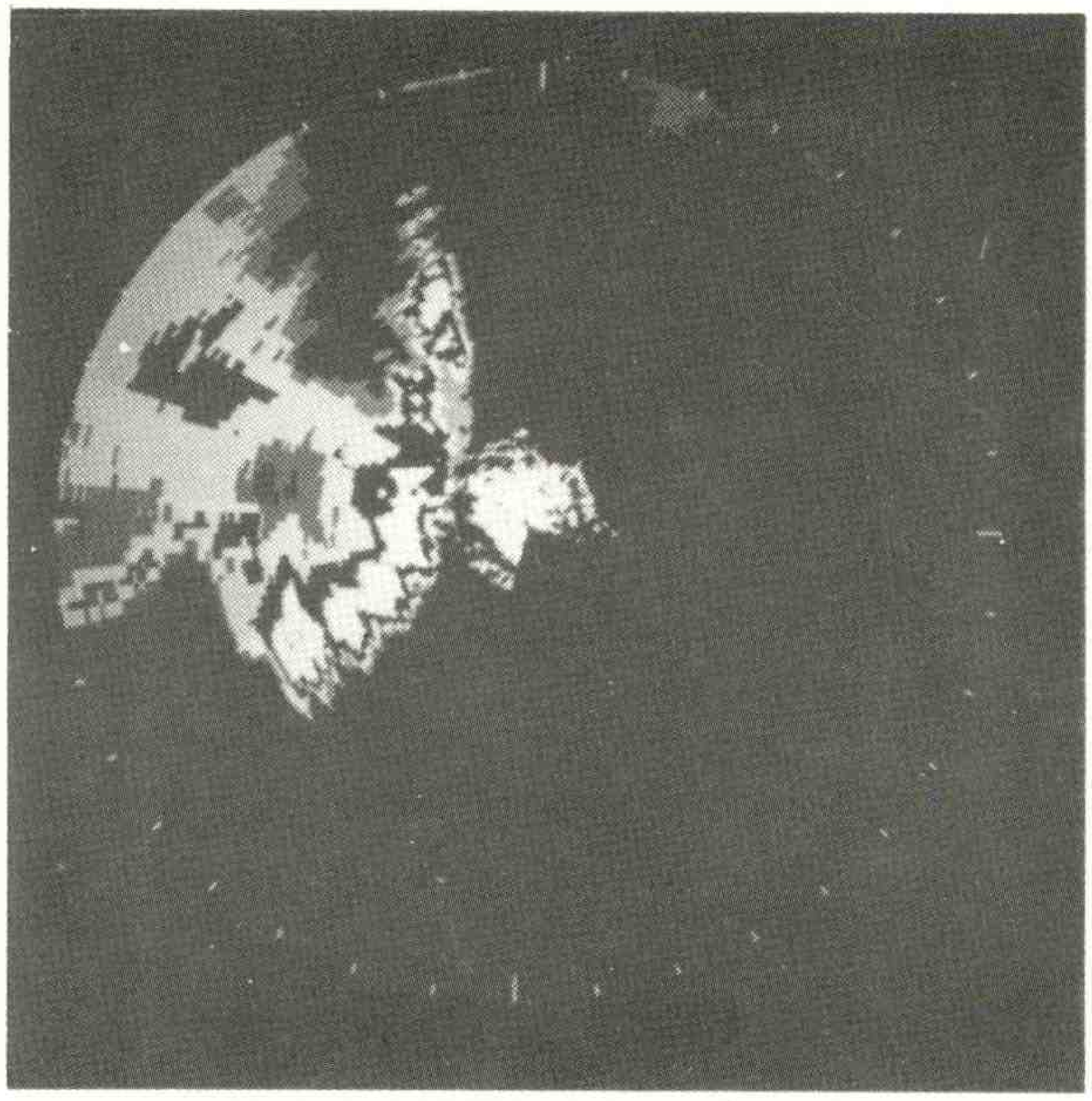


Figure 49. Remote radar display PPI, 200 km range, 2015 CST, June 16, 1975.

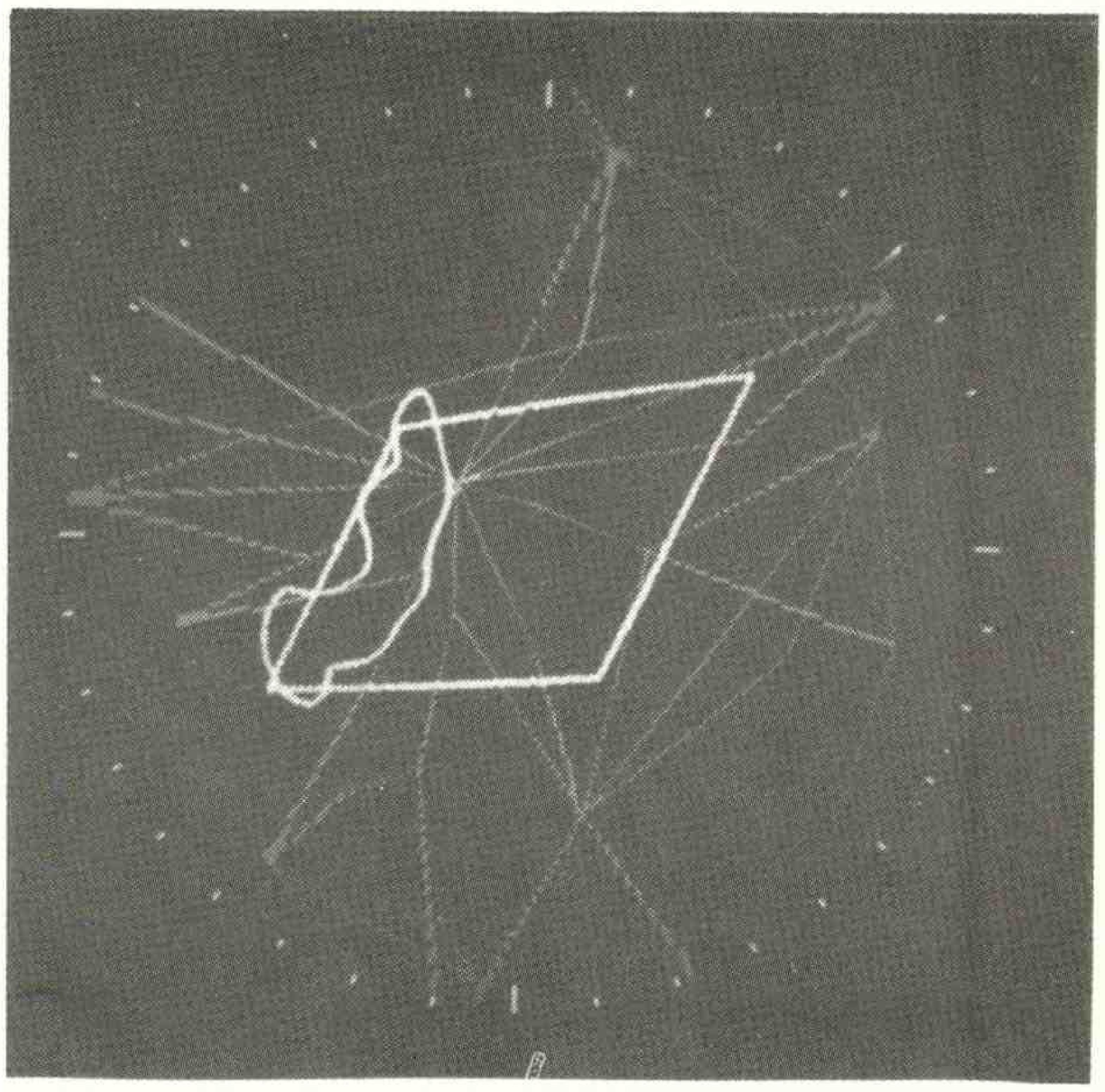


Figure 50. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 2015 to 2115 CST.

Figure 51. Remote radar display PPI, 200 km range, 2030 CST, June 16, 1975.

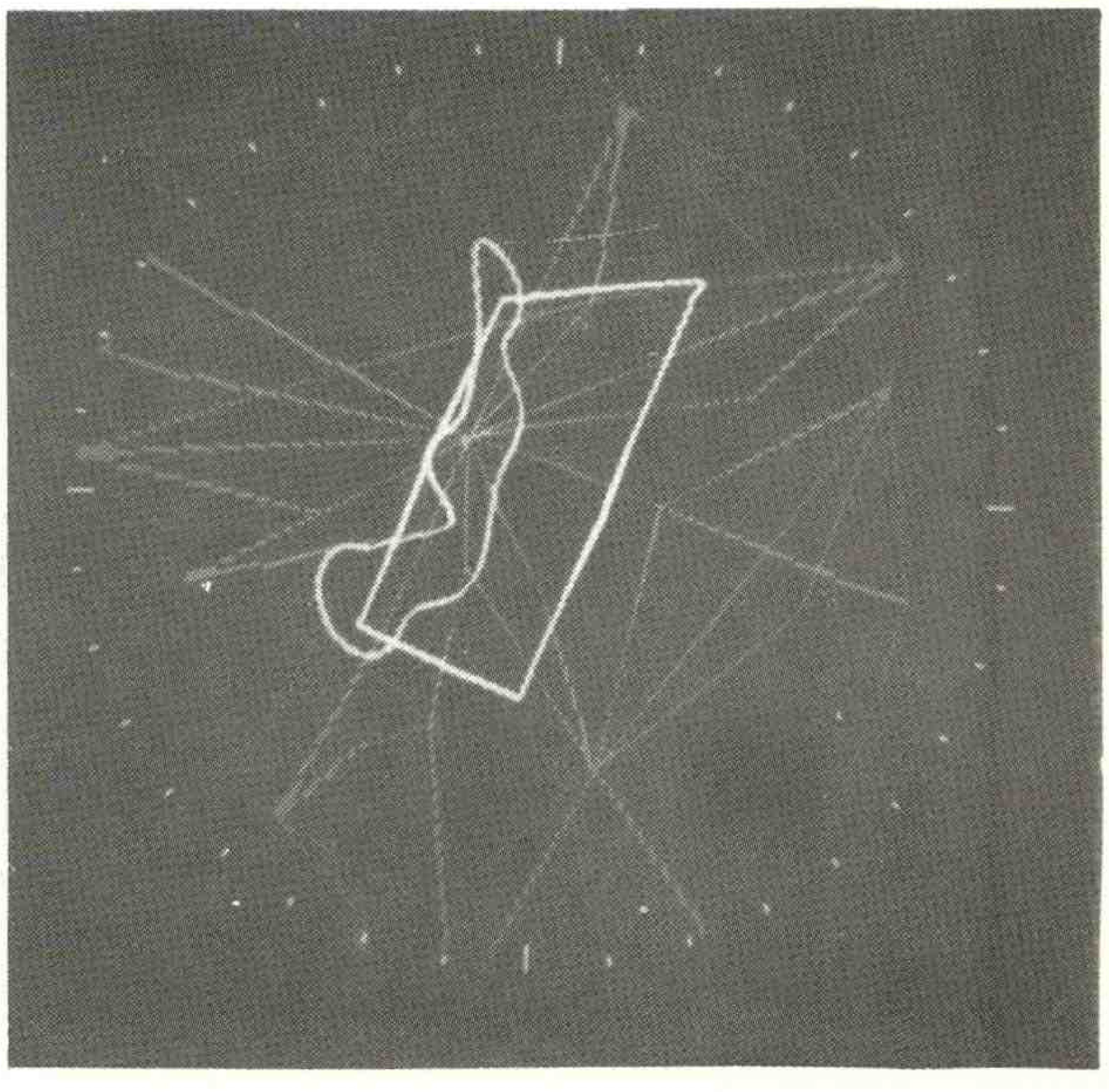


Figure 52. Remote radar display with computer generated warning area, echo contour and Victor airways, June 16, 1975. Prediction period is 2030 to 2130 CST.

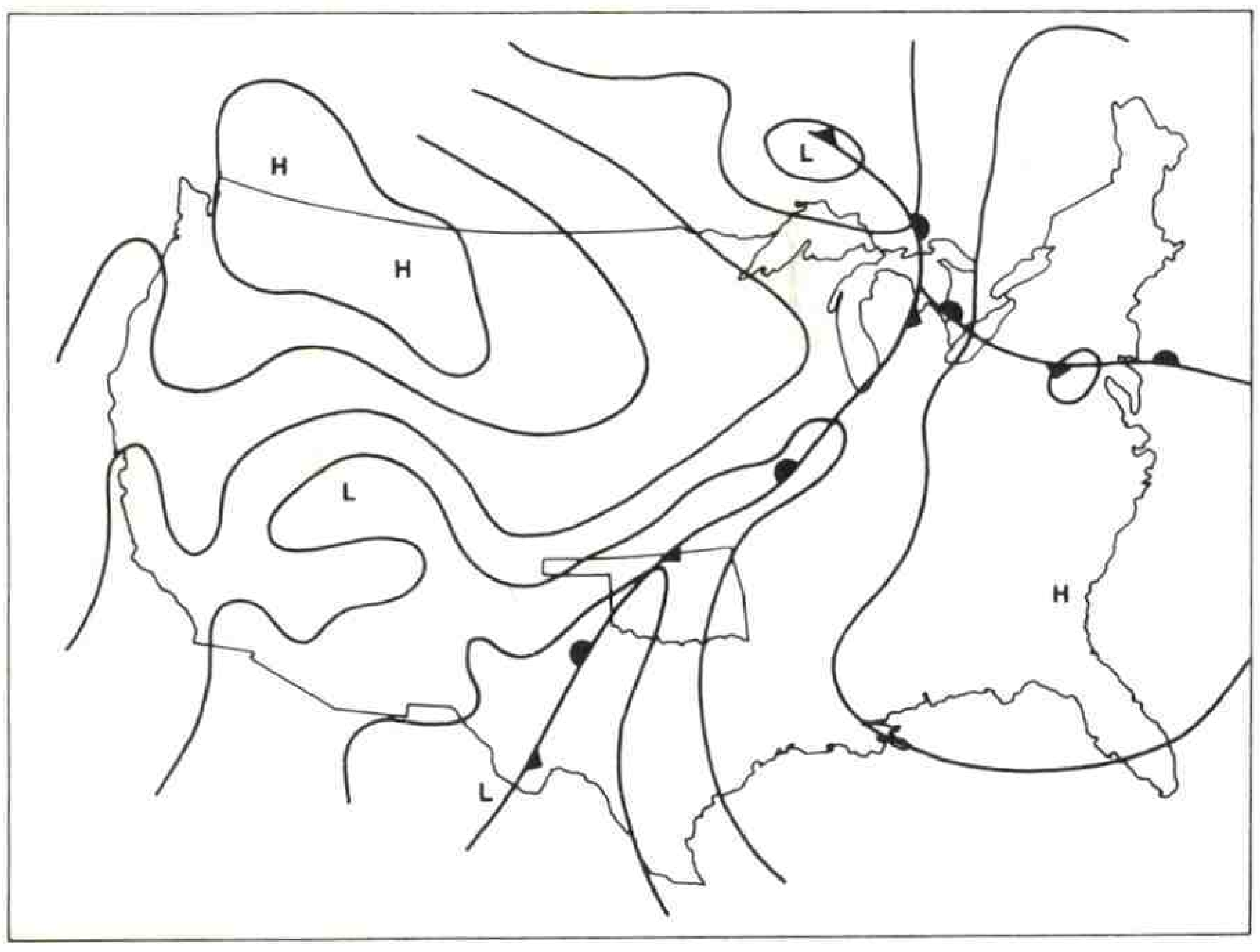


Figure 53. November 1, 1974, 12Z surface analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

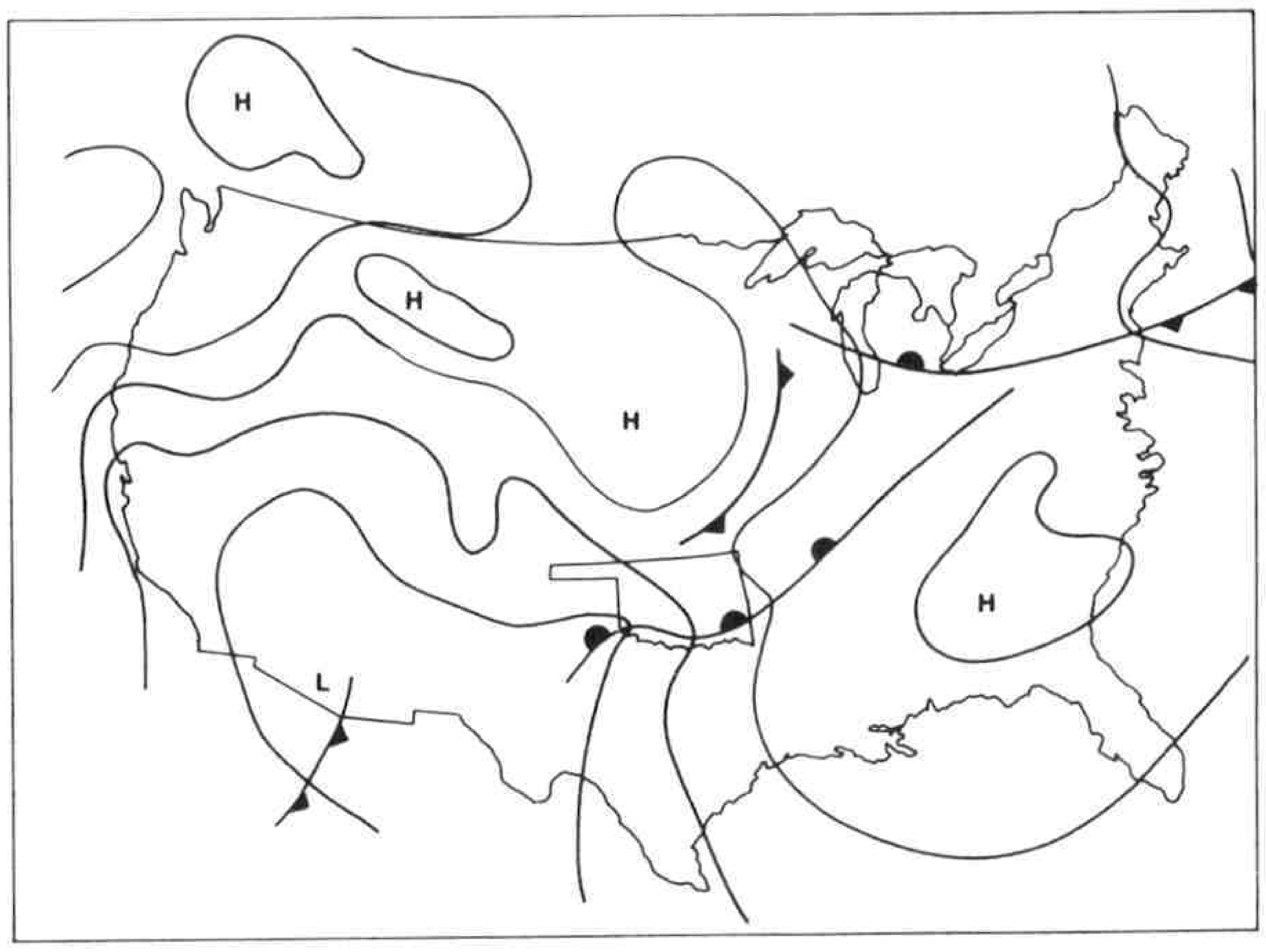


Figure 54. November 2, 1974, 12Z surface analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

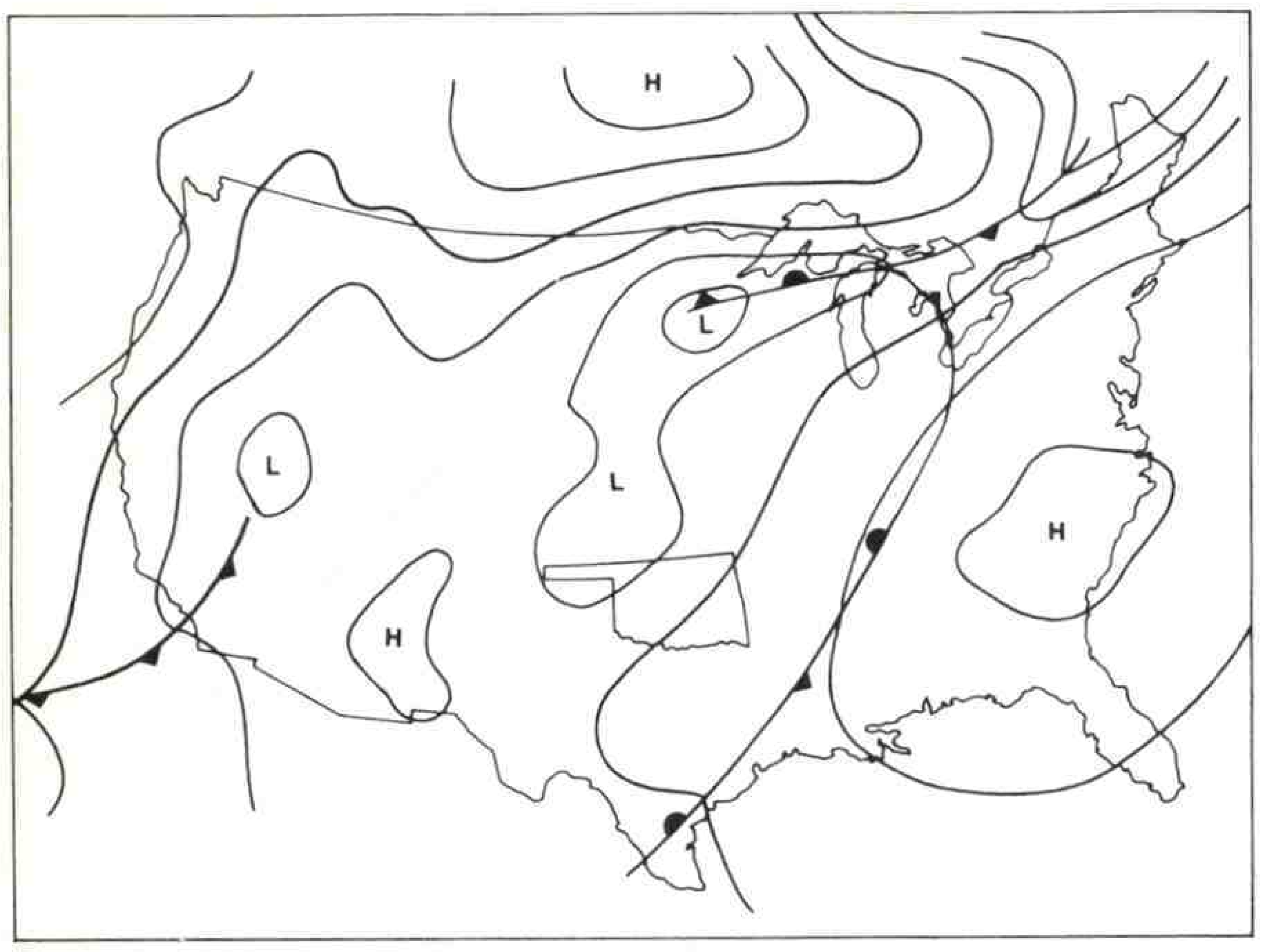


Figure 55. November 3, 1974, 12Z surface analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

low migrated northeastward into Canada; the other moved southward as a separate closed low. This resulted in a shift of the primary trough to a northeast-southeast orientation and caused the jet stream to retrograde westward (figs. 57 and 58). Since there was insufficient frontal lift and no surface heating, the triggering mechanism for the early morning storms on November 2 was probably a short wave, produced in the lee of the Rocky Mountains. Over central Oklahoma, mixing ratio values were 12-14 g kg^{-1}, and low clouds and high relative humidity were widespread (fig. 59). At 0600 CST, Oklahoma City reported a ceiling of 200 ft, Hobart and Clinton-Sherman, 150 km to the west, 200-300 ft ceilings, and Ardmore, 600 ft. At stations north of Oklahoma City, rain and fog were reported.

Surface winds were generally light 5-10 kt (fig. 59) which was unrepresentative of the mean flow. Surface mixing was not occurring, as indicated by the winds recorded at 444 m on the WKY tower (Goff and Zittel, 1974), which were 20-30 kts form the south-southeast. This flow more accurately reflects the true inflow into the storms.

Testing of the echo prediction logic began with the 1225Z observation and continued until 1210Z. In this case, digital radar data were available every two to three minutes. However, graphic displays were produced as

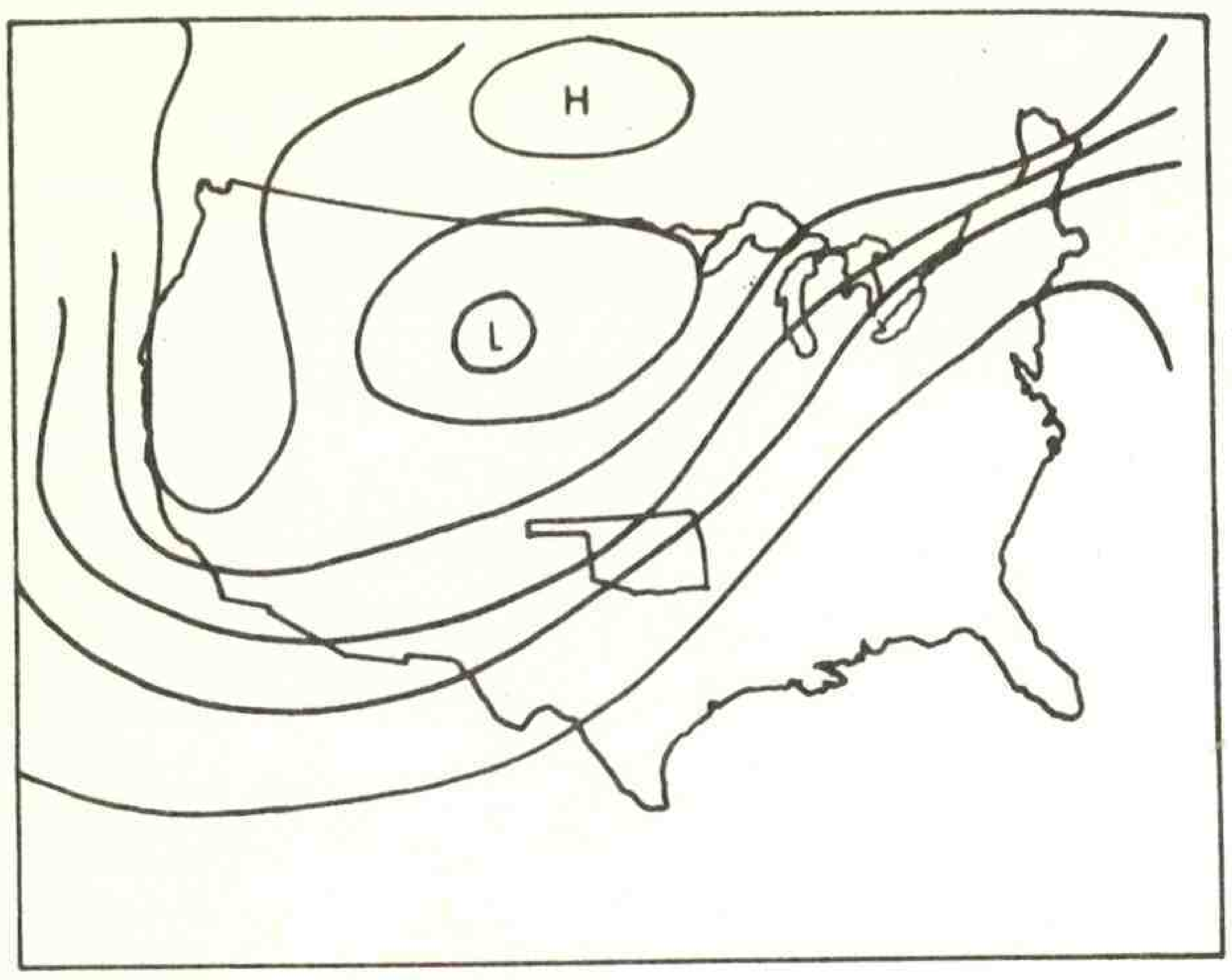


Figure 56. November 1, 1974, 12Z 500 mb analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

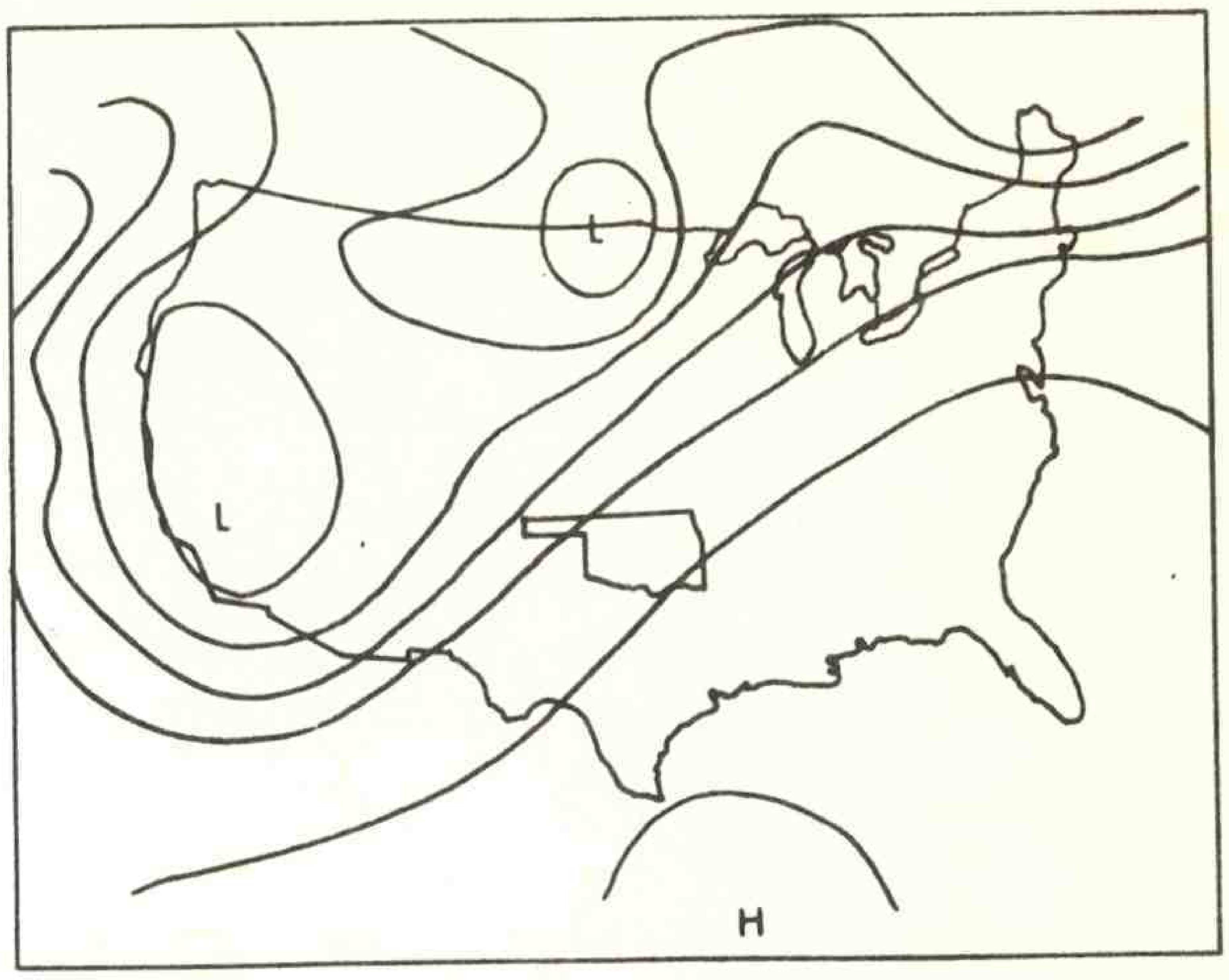


Figure 57. November 2, 1974, 12Z 500 mb analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

before at approximately five minute intervals. The thresholds for intensity and area were 40 dBZ (intensity switch 4) and 150 km^2, respectively. The coding of gray shades for photography was 1220333. The time weight constant was 2400 and the minimum range (to omit ground clutter) was 20 km.

Because the radar pattern changed little during the 45 minutes of tracking, only selected radar PPIs and graphic PPIs are shown for this case (figs. 60 through 69).

Warning areas were drawn for a one-hour prediction interval starting from the time of the last observation.

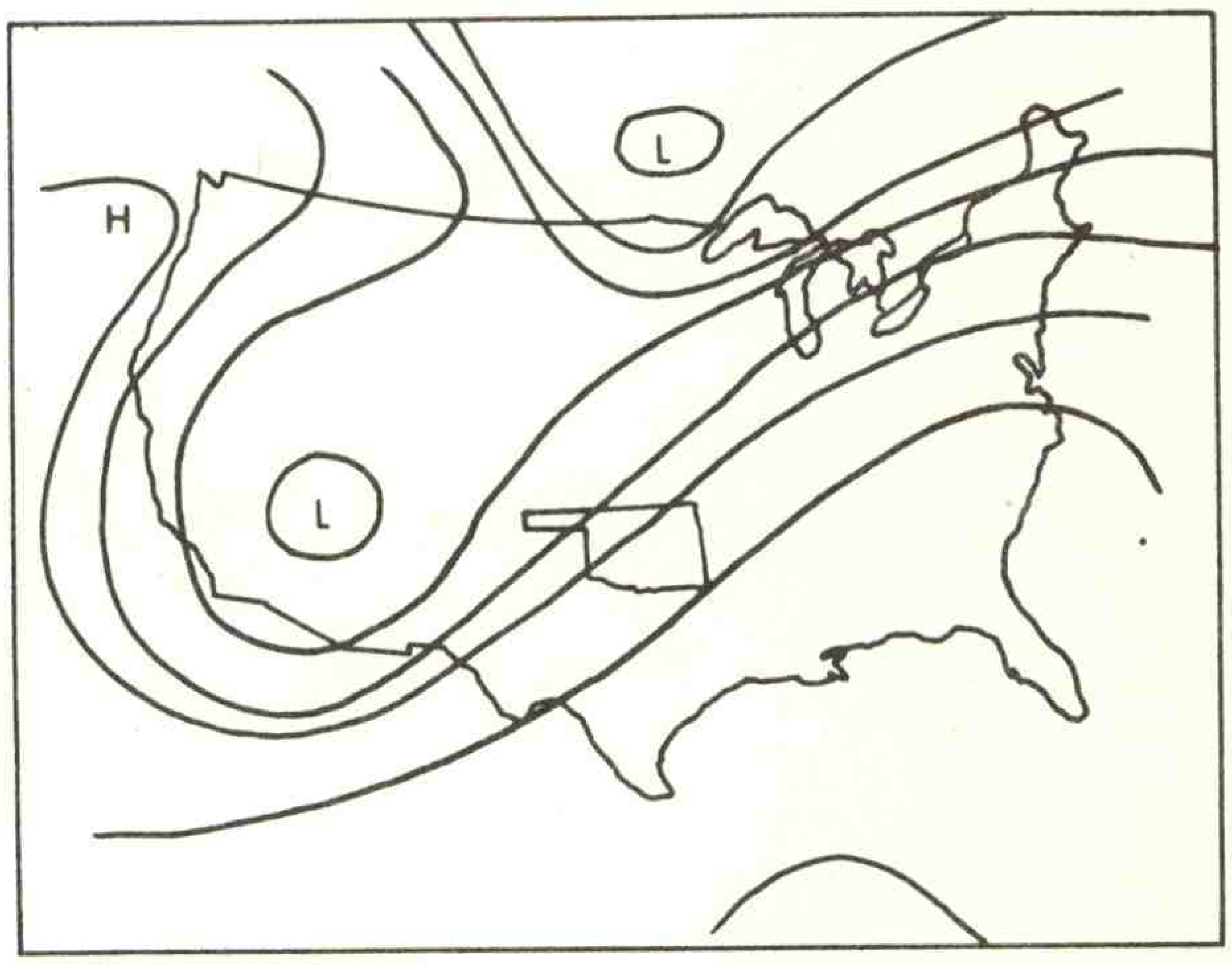


Figure 58. November 3, 1974, 12Z 500 mb analysis adapted from DOC, NOAA, EDS daily weather maps, Weekly Series.

In the first PPI at 1225Z, two cells were isolated and labeled cell 1 and cell 2, respectively. Cell 1, at 250 degrees azimuth and 76 km range, was tracked for the entire 45 minute period. As shown in Table 4, excluding the first prediction, cell motion was southeasterly gradually shifting to the northeast and accelerating. By 1310Z, cell motion was from 220 degrees azimuth at 53 km hr^{-1}.

Cell 2 split after the first PPI becoming two cells. These merged later at 1234Z and tracking of cell 2 was resumed (table 4). This cell, imbedded in the line northwest of Oklahoma City, moved from 240 degrees azimuth about

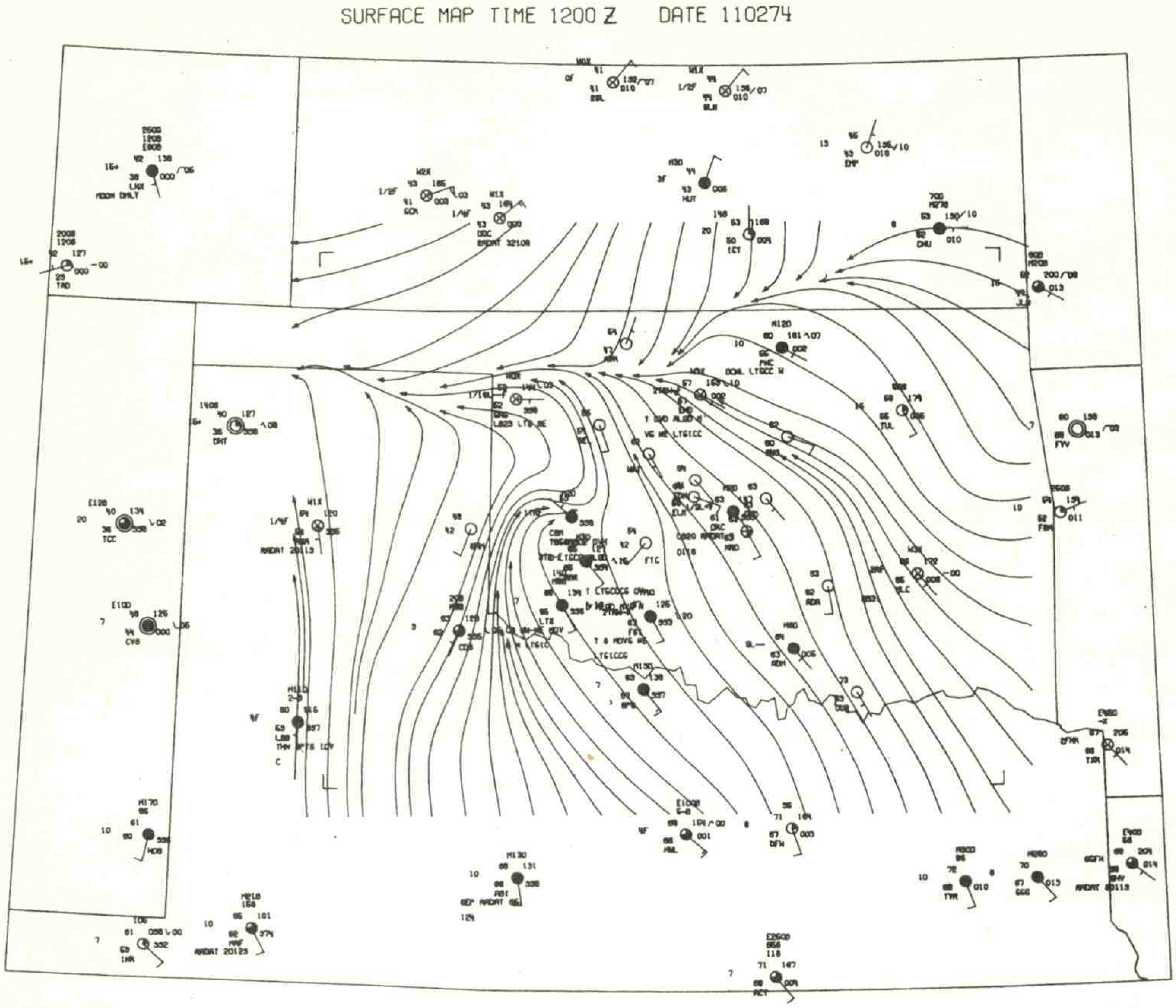


Figure 59. Subsynoptic surface data provided by NWS, FAA and NSSL stations, 1200Z. November 2, 1974, with streamlines superimposed.

60 km hr^{-1}. At 1245Z when a sudden increase in the line's area occurred, cell 2 was dropped.

After cell 2 split at 1228Z, one of the new cells was labelled cell 3 and tracked until 1234Z. The other cell was never tracked because little motion was shown.

Cell 5 was isolated at the north end of the line at 1230Z and tracked for 15 minutes. During that time it moved from a more southerly direction (214 degrees) than the other cells.

At 1245Z, a much larger cell was isolated due to the increase in intensity and size. This cell, cell 6, was tracked until testing ceased at 1310Z.

As has been pointed out in previous sections, the large values for σ_t and σ_d (table 4) are in part the result of too frequent sampling. In some cases, the graphics examples do not show the high values of σ_t and σ_d because they exceeded the predetermined limits, as mentioned in case 1.

Table 4. Echo centroid positions, direction and speed predicted, and the RMSE values for November 2, 1974.

ECHO NO.	TIME (Z)	AZIMUTH (DEGREES)	RANGE (KM)	DIRECTION (DEGREES)	SPEED (KM HR^{-1})	σ_d (KM)	σ_t (HOUR)
1	1225	251.	76.	-	-	-	-
2	1225	311.	95.	-	-	-	-
1	1228	250.	75.	303.3	33.1	-	-
3	1228	304.	95.	-	-	-	-
1	1230	251.	74.	256.0	23.8	27.41	0.803
3	1230	306.	95.	215.0	98.8	-	-
5	1230	349.	126.	-	-	-	-
1	1232	249.	73.	283.1	30.8	43.72	0.755
5	1232	350.	127.	235.1	72.5	-	-
1	1234	249.	71.	278.3	36.6	41.90	0.729
2	1234	315.	92.	247.7	47.9	-	-
5	1234	349.	127.	168.9	15.0	15.84	1.060
1	1236	249	70.	274.1	37.3	38.72	0.675
2	1236	317.	92.	242.8	53.3	20.54	0.502
1	1238	250.	69.	265.2	35.6	39.77	0.675
2	1238	319.	91.	242.1	59.6	17.93	0.619
5	1238	351.	130.	214.7	40.9	36.72	1.329
1	1240	250.	68.	259.9	34.6	37.31	0.635
2	1240	320.	90.	243.2	61.7	18.14	0.556
1	1242	250.	67.	256.7	34.0	35.21	0.601
2	1242	322.	90.	242.5	64.9	18.45	0.546
1	1245	250	64.	254.1	35.8	33.48	0.618
6	1245	311.	83.	-	-	-	-
1	1247	251.	63.	250.5	36.4	33.63	0.593
5	1247	310.	81.	346.1	74.1	-	-
1	1249	252.	61.	246.8	37.8	33.45	0.599
6	1249	313.	80.	268.5	62.2	69.93	0.944
7	1249	353.	132.	-	-	-	-
1	1251	255.	60.	240.6	39.0	40.84	0.576
6	1251	312.	80.	271.2	39.4	62.41	1.099
1	1253	256.	59.	236.1	39.9	39.81	0.555
6	1253	314.	79.	260.7	43.3	58.90	1.076
1	1255	259.	57.	231.4	41.9	41.75	0.624
6	1255	315.	80.	248.2	41.6	57.34	1.015
1	1257	260.	54.	228.9	44.4	40.65	0.677
6	1259	319.	80.	237.8	54.6	57.82	1.402
1	1259	262.	52.	227.1	46.9	39.60	0.685
6	1259	320.	79.	236.7	59.5	54.73	1.313
1	1300	261.	51.	226.7	48.3	42.70	0.680
6	1300	322.	80.	234.2	65.0	57.53	1.359
1	1302	267.	51.	224.3	50.2	50.80	0.701
6	1302	324.	81.	231.5	69.2	55.49	1.292
1	1304	269.	50.	222.3	51.8	49.67	0.685
6	1304	326.	82.	229.2	72.6	53.43	1.235
1	1306	270.	49.	221.0	52.8	48.48	0.670
6	1306	327.	81.	229.0	73.3	52.15	1.190
1	1308	267	47.	221.1	52.9	51.53	0.710
6	1308	328.	81.	229.0	72.6	50.14	1.149
1	1310	270.	46.	220.9	53.2	50.72	0.699
6	1310	328.	80.	229.8	69.8	48.96	1.143

Figure 60. Remote radar display PPI, 200 km range, 1225Z, November 2, 1974.

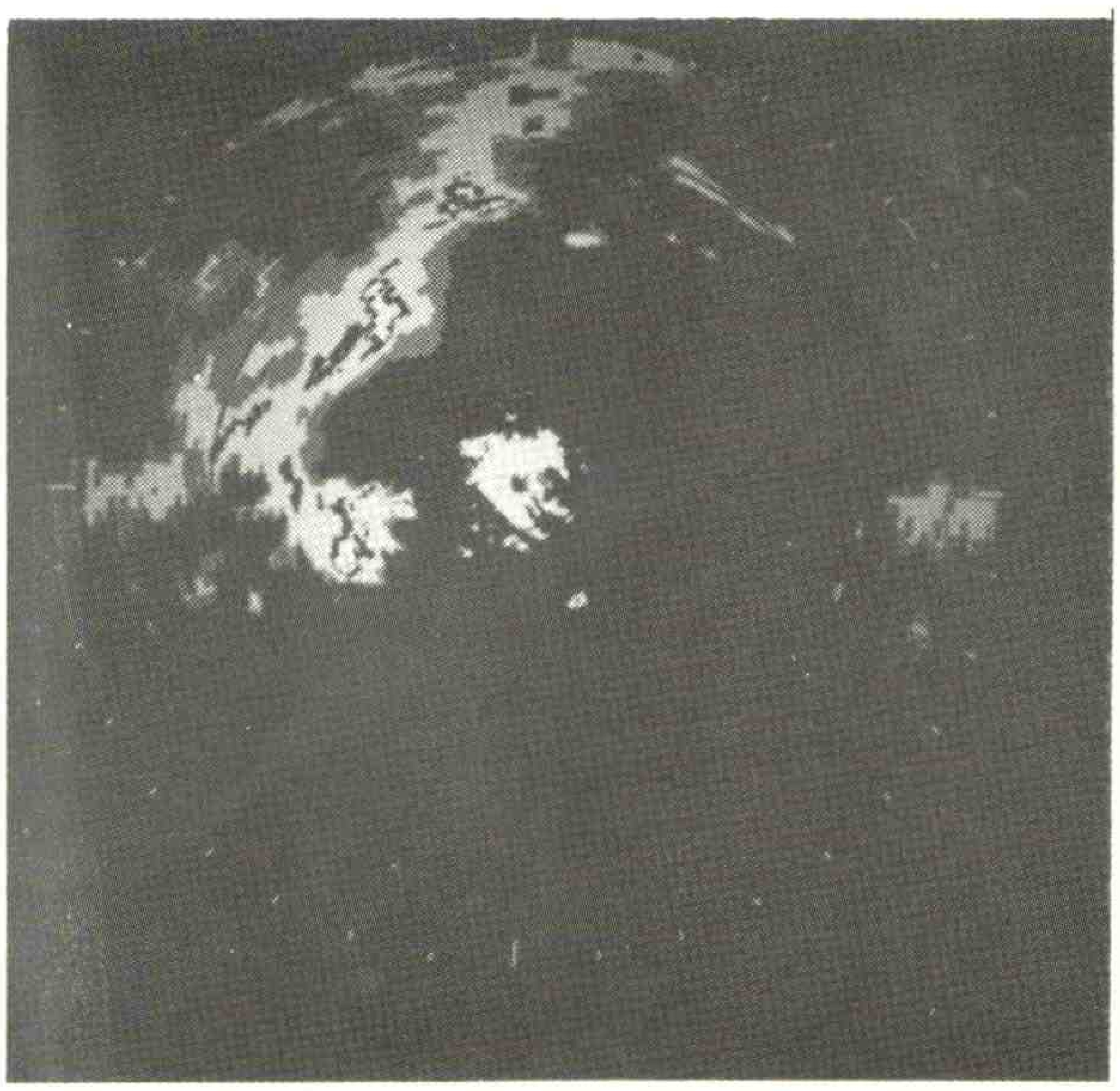


Figure 61. Remote radar display PPI, 200 km range, 1230Z, November 2, 1974.

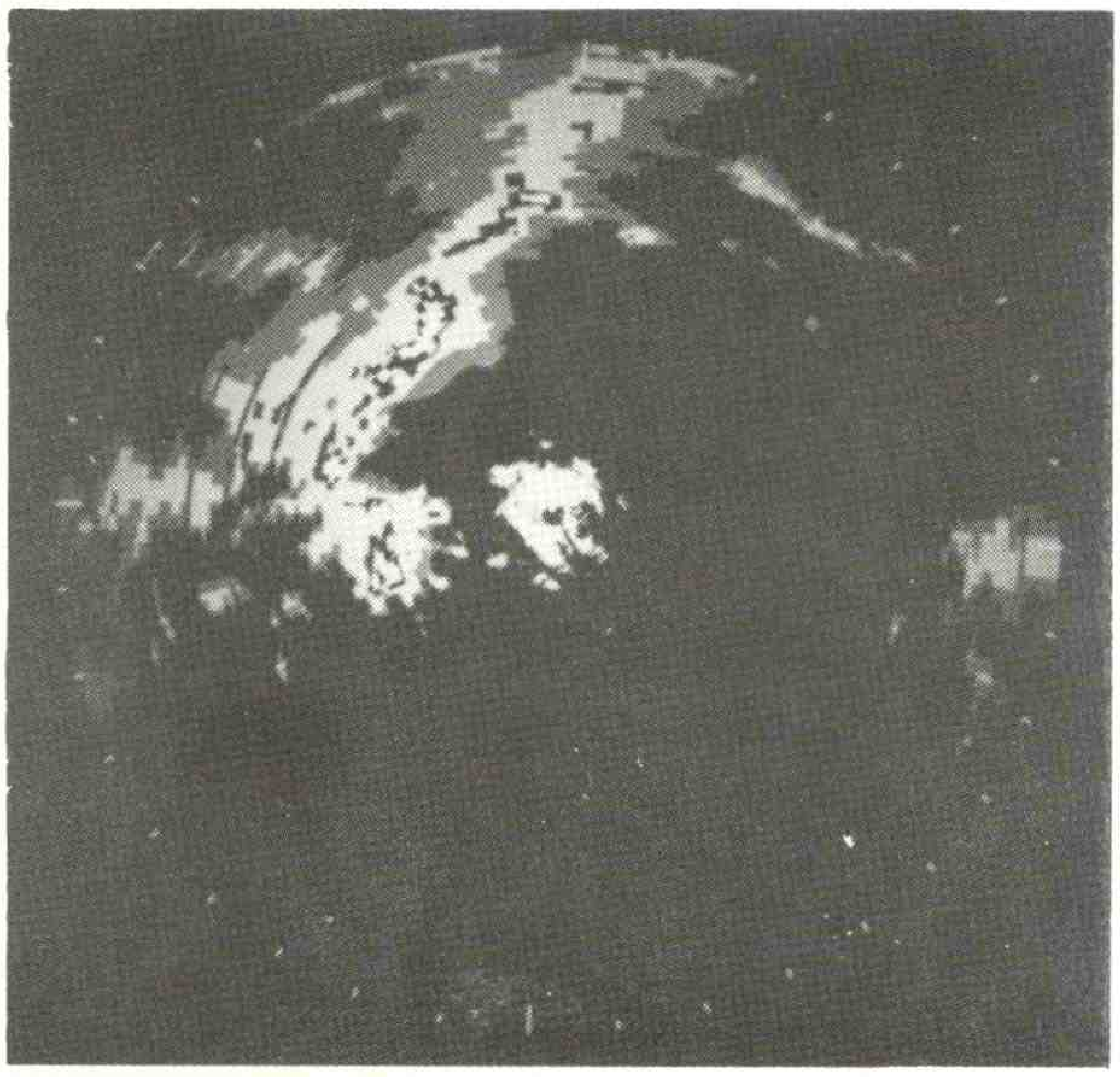


Figure 62. Remote radar display PPI, 200 km range, 1240Z, November 2, 1974.

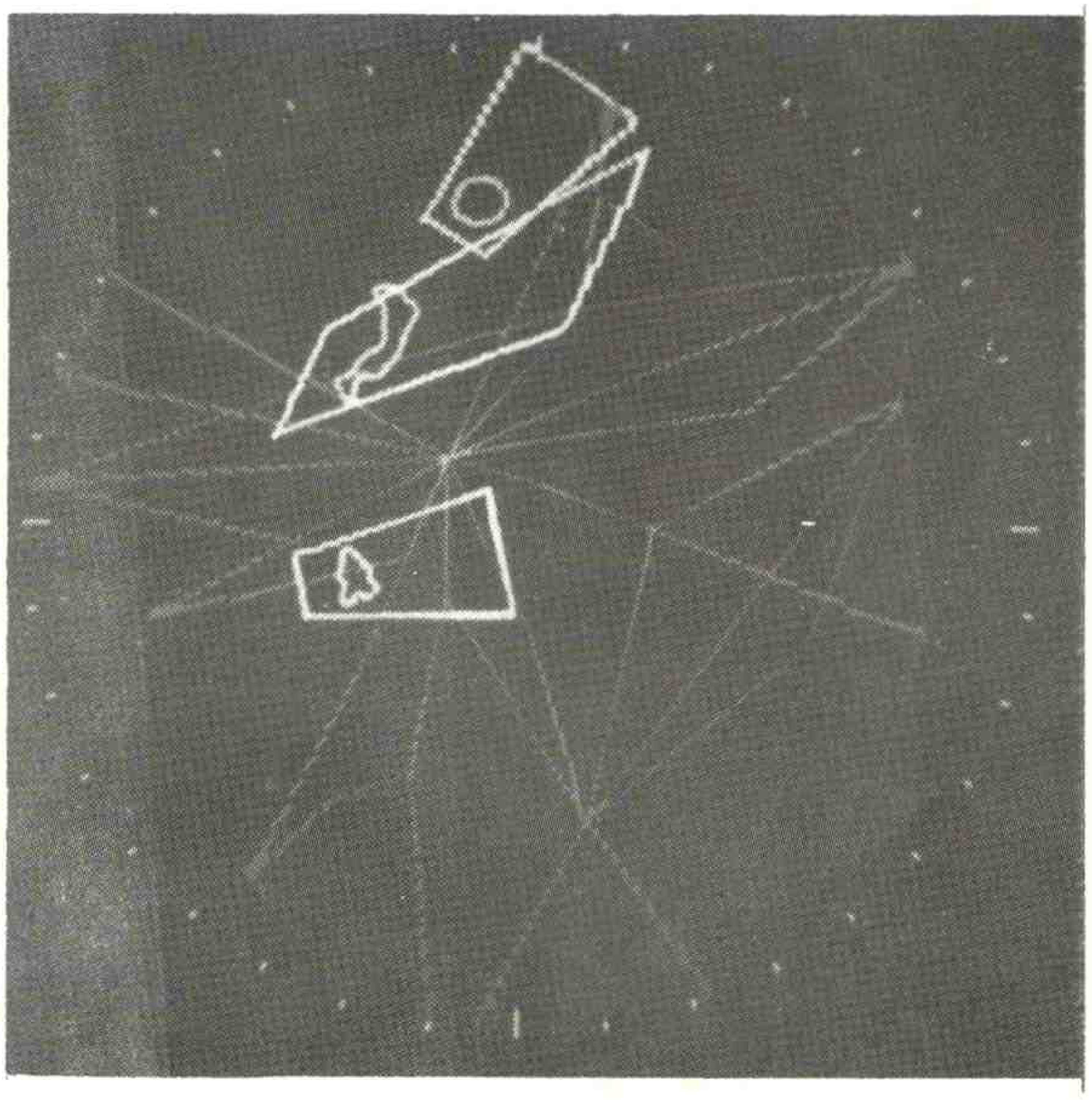


Figure 63. Remote radar display with computer generated warning areas, echo contours and Victor airways, November 2, 1974. Prediction period is 1240 to 1340Z.

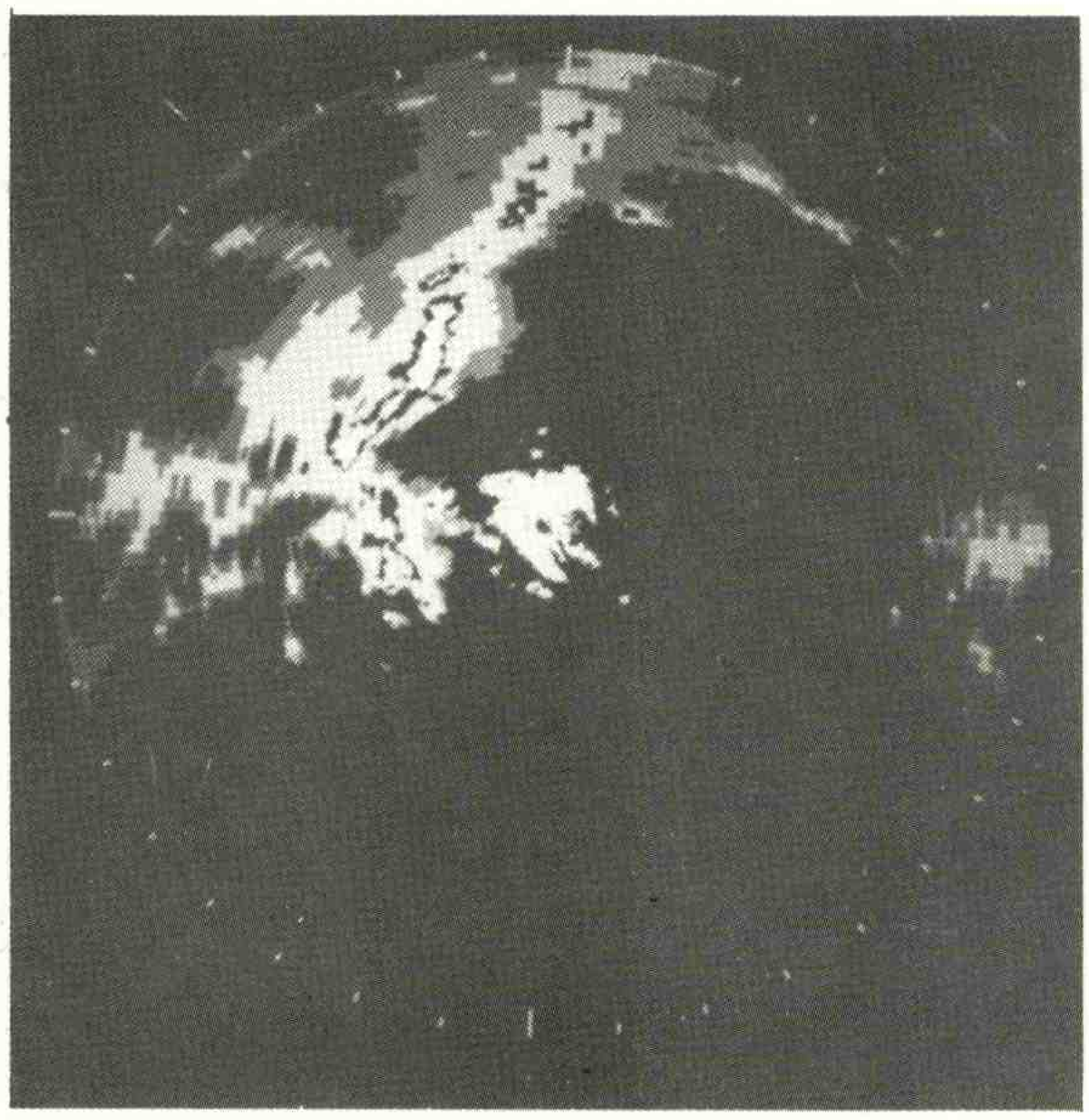


Figure 64. Remote radar display PPI, 200 km range, 1251Z, November 2, 1974.

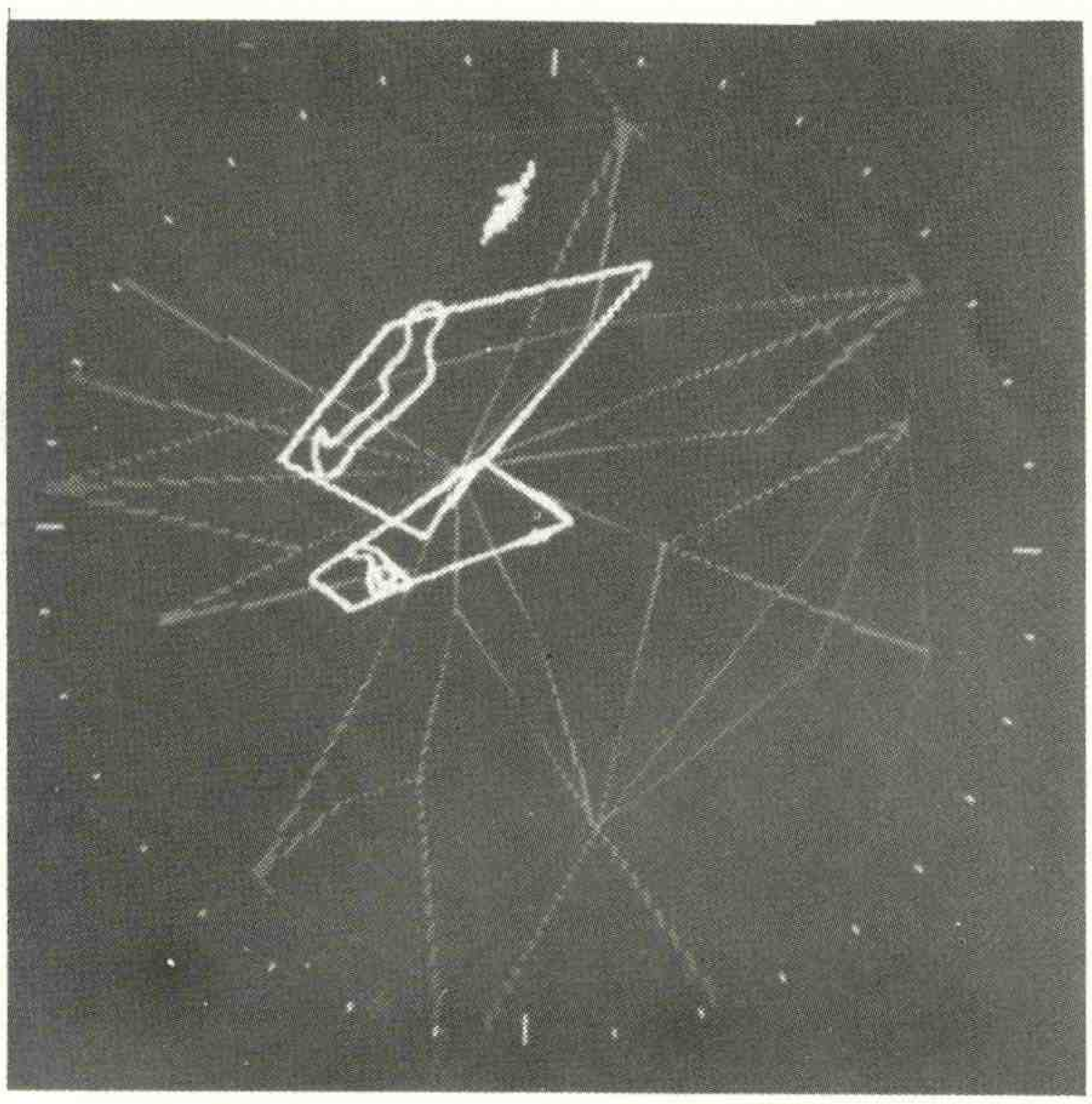


Figure 65. Remote radar display with computer generated warning areas, echo contours and Victor airways, November 2, 1974. Prediction period is 1251 to 1351Z.

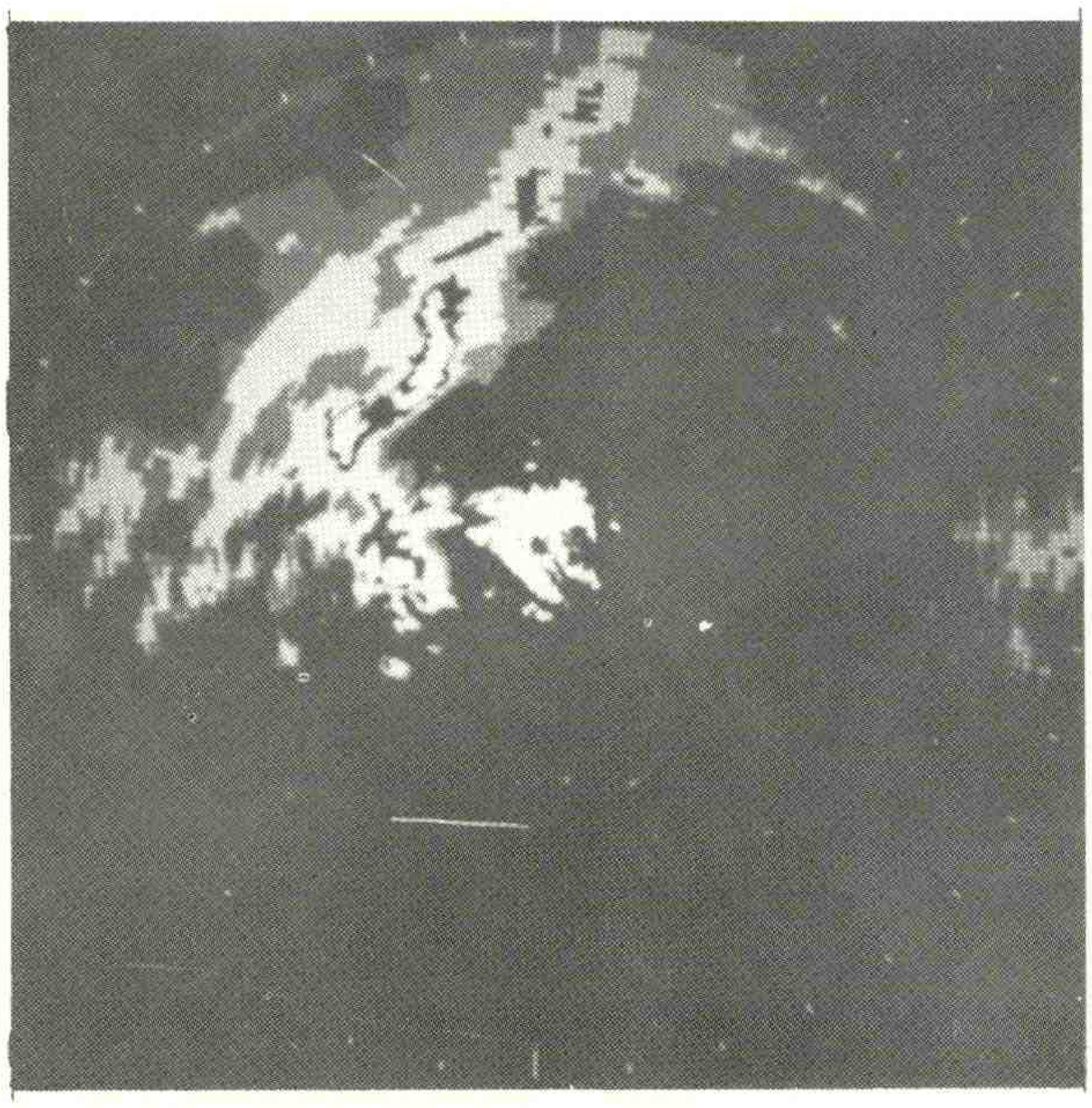


Figure 66. Remote radar display PPI, 200 km range, 1300Z, November 2, 1974.

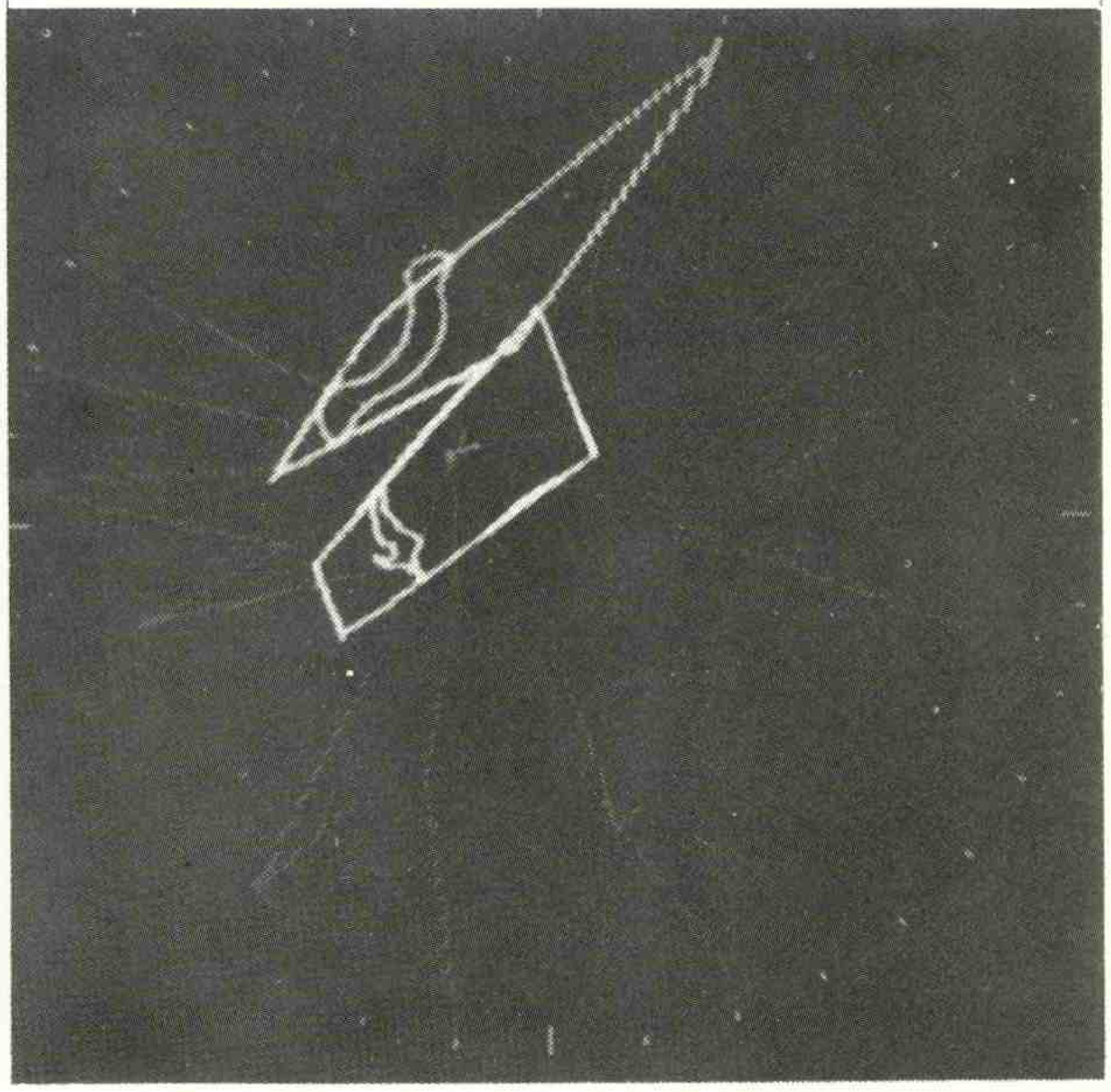


Figure 67. Remote radar display with computer generated warning areas, echo contours and Victor airways, November 2, 1974. Prediction period is 1300 to 1400Z.

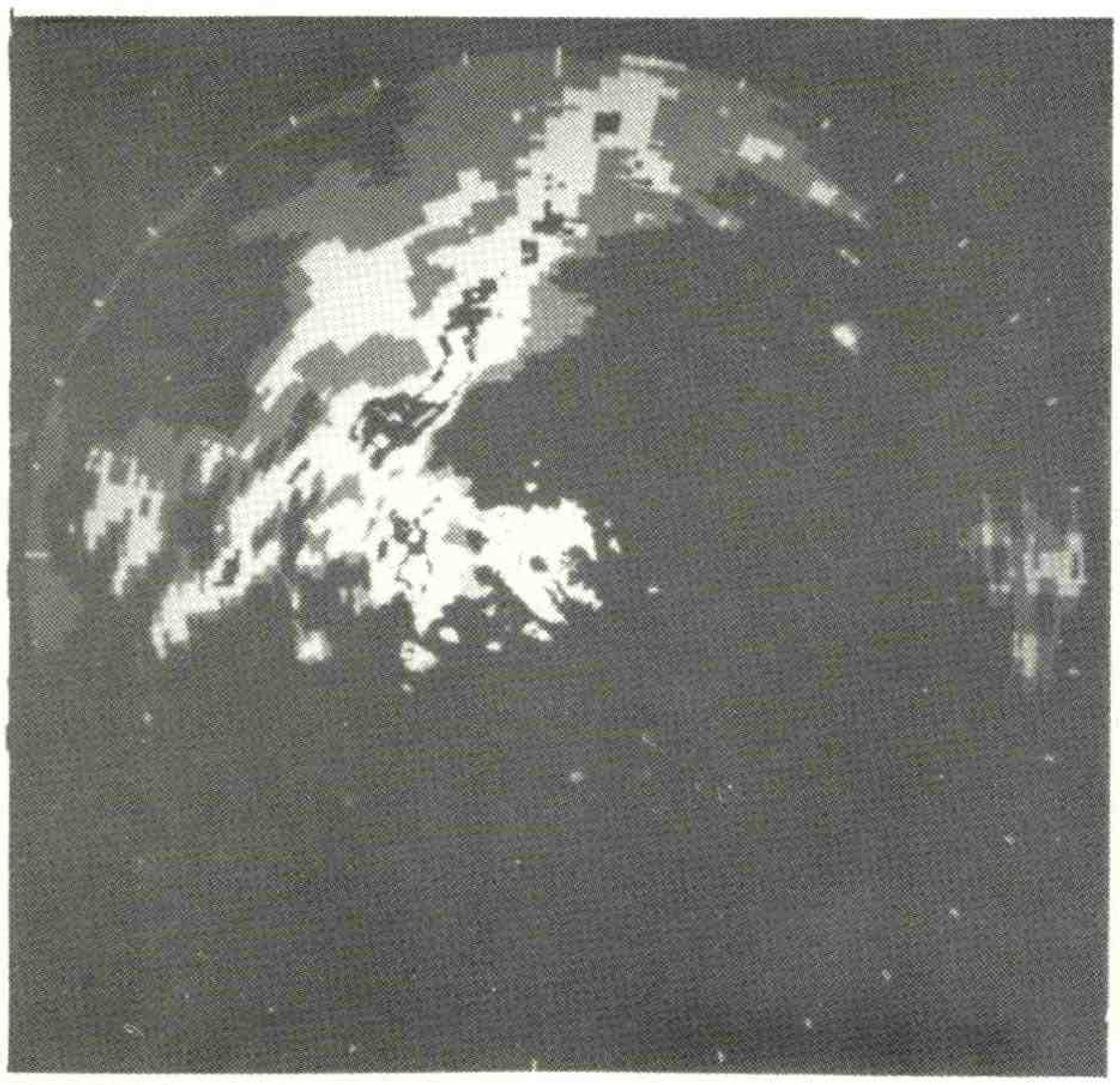


Figure 68. Remote radar display PPI, 200 km range, 1310Z, November 2, 1974.

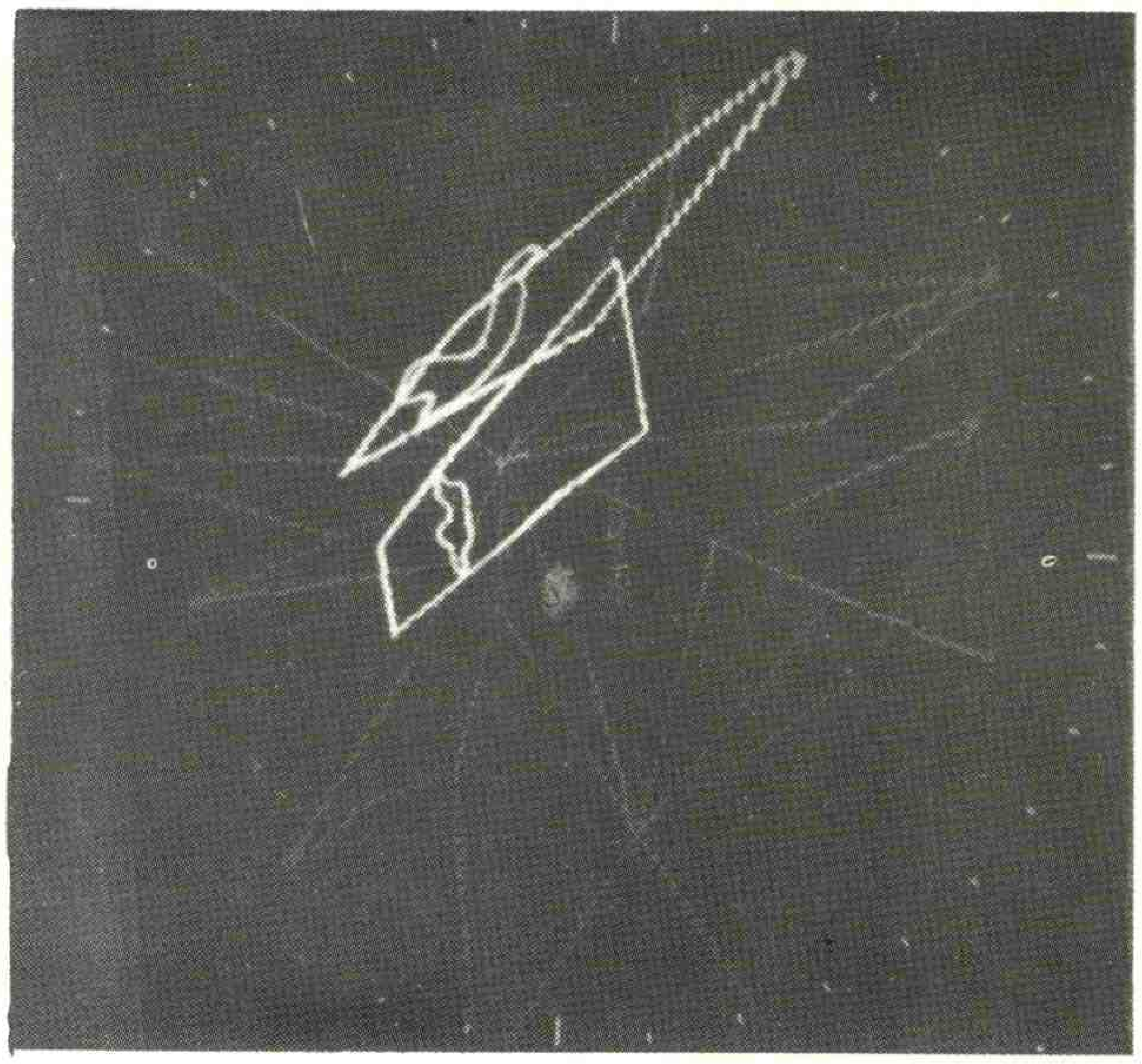


Figure 69. Remote radar display with computer generated warning areas, echo contours and Victor airways, November 2, 1974. Prediction period is 1310 to 1410Z.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations included here are divided into three areas: A) Phase II objectives, B) software refinements, and C) future tests and suggestions for implementation.

A. Phase II Objectives

After consideration of research on storm motion and predictability in progress at NSSL, Lincoln Laboratories, Massachusetts Institute of Technology, and the National Weather Service Techniques Development Laboratory, we conclude that statistical techniques for automation of tracking and warning procedures are incomplete and probably will require substantial improvements in hardware (e.g., more sophisticated radars and signal processing equipment) and significant changes in the operational configurations of manpower. We believe that until such time as our ability to measure and understand severe storm dynamics, a simplified man-machine mix using echo centroids for tracking and extrapolating echo motion represents the best technique for issuing advisories at the Flight Service Station.

We also believe that the remote terminal described in Phase I is an adequate method for remotely displaying radar imagery; and the Phase II study has demonstrated the feasibility of using the R, θ, coordinate system as a graphics terminal. To this end we have developed logic which:

1. Shows current echo positions and coverage by displaying contoured echoes at user defined area and intensity threshold and shows that echoes from severe storms can be isolated routinely using an intensity threshold of 30-40 dBZ and an area threshold of 150-1000 km^2. This threshold is sensible because ninety-nine percent of the storms with hail have a maximum intensity above 30 dBZ and moderate turbulence can be expected in storms of that intensity.

2. Displays a graphic warning area which is derived from echo size and motion and expanded downstream for a user specified prediction interval to show a measure of the storm's predictability.

3. Provides the user a choice of two computer-generated background reference maps -- the State of Oklahoma outline, suitable for a 400 km range display, and the low level Victor airways, suitable for a 200 km range display. Other maps can be added with only a slight impact on the existing logic.

4. Achieves high visibility and easy interpretation by using different grey shades for the graphics elements. The best results were achieved when the warning areas were coded "bright", the echo contours coded "medium", and the reference maps coded "dim".

What we have not done is to:

1. Generate alphameric messages on the remote radar display system. Although possible, this was rejected for three reasons:

a) degradation of the display's resolution as a function of range would require excessively large characters to maintain readability; b) the logic would be complex, time consuming and require additional core, and c) low cost, high speed alphameric displays are available for use as a satellite display.

2. Transmit simulated real time test cases of the graphics products to the Wiley Post FSS. However, their personnel were kept informed of our work and on occasion did have an opportunity to see a simulated test case at NSSL. Reactions were quite favorable to the graphics described above.

3. Incorporate growth and decay trends within the graphics. They were found to be, on a storm-by-storm basis, too short-lived to extrapolate. General statistics, such as echo coverage, average intensity, etc., were not acceptable to FSS briefers as guidance information.

B. Software Refinements

The computer techniques used for this report have proved reliable and stable and no major modifications are suggested. Small changes will be necessary to facilitate real time operation and improve aesthetic appearances. Although developed for an R, θ coordinate system, the logic can be adapted with a considerable modification effort to an X,Y type display. Additional modifications of existing logic might include:

1. Creating a permanent file for the echo shape function so that a contoured echo, regardless of the time of the last entry, will retain its shape.

2. Converting the logic to determine the airports in the paths of echoes from a cone to the rectangular area used for generating warning areas. (It may be desirable to perform the airport search within the program area which generates graphics.)

3. Routing radar PPI information into the computer for blending with background reference fields before displaying on the remote terminal. This would require a hardware change and should be switch controllable to avoid computer dependency.

4. Including the echo's depth when drawing a warning box. The contour of large, slow moving echoes may actually circumscribe a box under the existing logic.

5. Introducing the weighting function into the calculations of σ_t and σ_d. Currently, only the centroid positions are weighted to have decreasing influence with time. However, the errors ε_t and ε_d should also have decreasing influence with time. We know that with few points to estimate echo motion, the errors will be large. However, as more points are added we should not be penalized by the large earlier errors. Conversely, if having tracked a storm for

awhile, its predictability decreases, we should be made aware of this fact.

6. Dividing the scope into sectors. Some program speed-up could probably be realized if certain quadrants did not have to be scanned for echo.

C. Future Tests and Suggestions for Implementation

Based on experience with the three case studies, the author believes some skill is needed to use the echo centroid tracking logic presented in this report. Basic to a successful operation is the selection of area and intensity thresholds and sampling intervals for the different types of storm situations (e.g., isolated severe storms, squall lines, and slow moving flood producers). We believe that some training of FSS personnel will be needed.

A second consideration is the configuration between man and machine. One possibility is to have one person responsible for identifying the hazardous storms and operating the echo tracking logic. Then, all user (pilot briefer) requests are channeled to the "hazards" briefer who is cognizant of the complete echo pattern. A second possibility is to allow each pilot briefer access to a computer terminal which lists input and output of echo locations and velocities (e.g., echoes which have been assigned user numbers for tracking could be so labeled).

One very important question which needs to be answered is how much time is needed for decision making. Not only initially when establishing thresholds, but during operation when matching echoes manually. This, of course, will vary with radar patterns of differing complexity. (The author had the advantage of being able to study the numerical results at leisure, but was handicapped by not having a simultaneous radar display for comparison.)

For the above reasons, a limited operational test is needed. This test should be divided into two sections of one month's duration each during a storm season. The first half of the test would be to prepare software logic for operational use and to test (a) the feasibility of operationally using the existing logic, and (b) determining the optimum man-machine configuration. It should include sufficient hardware (e.g., remote alphameric terminal connected to a time share larger computer) to allow efficient operation of the ECHOPRED logic without major modifications.

If the outcome of the first test is favorable, the system should then be installed at a Flight Service Station, such as Wiley Post, for operational test and evaluation by FSS staff.

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REFERENCES

Barclay, P. A., and K. E. Wilk, 1970: Severe thunderstorm radar echo motion and related weather events hazardous to aviation operations. ESSA Tech. Memo. ERLTM-NSSL 46, 63 pp.

Bigler, S. G., 1969: Dial A Radar. Bulletin, AMS, 50, 6, 428-430.

Blackmer, R. H., Jr., and R. O. Duda, 1972: Application of pattern recognition techniques to digitized radar data. Proceedings, 15th Radar Met. Conf., AMC, Boston, Mass., 138-143.

Goff, R. C., and W. D. Zittel, 1974: The NSSL/WKY-TV tower data collection program: April-July 1972. NOAA Tech. Memo. ERL NSSL-68, 45 pp.

Kessler, E., and J. T. Russo, 1963: Statistical properties of weather radar echoes, Proceedings, Wea. Radar Conf., AMS, Boston, Mass., 25-33.

Morris, M., and O. E. Brown, 1937: Analytic Geometry. McGraw-Hill Book Co., New York, 144 pp.

Östlund, S. S., 1974: Computer software for rainfall analyses and echo tracking of digitized radar data, NOAA Tech. Memo. ERL-WMPO-15, 82 pp.

Sirmans, D., and R. J. Doviak, 1973: Meteorological radar signal intensity estimation. NOAA Tech. Memo. ERL NSSL-64, 80 pp.

Wilk, K. E., 1966: Motion and intensity characteristics of the severe thunderstorms of April 3, 1964. ESSA IERTM-NSSL 29, 9-21.

Wilk, E. E., and K. C. Gray, 1970: Processing and analysis techniques used with the NSSL weather radar system. Proceedings, 14th Wea. Radar Conf., AMS, Boston, Mass., 369-374.

Wilson, J. W., 1966: Movement and predictability of radar echoes, ESSA Tech. Memo. ERLTM-NSSL 28, 30 pp.

APPENDIX A

Annotated Command Structure, June 6, 1975

```
COMMAND
TWC
HHMM
24ØØ

COMMAND
GCD
2Ø

COMMAND
ACC

AREA/INTENSITY
 25Ø     4

DAY/  TIME/  TILT
157   2Ø4Ø      Ø


 2 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
 988        29     136 cell 1 - new  { will try tracking only very strong
1907       335     157 cell 2 - new  { (VST) cells this run


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
 5Ø1       327     161      ignore severe cells imbedded in the
 359       34Ø     155      VST cells above

DAY/  TIME/  TILT
157   2Ø45      Ø
STOP


 2 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SC KM

AREA/AZIMUTH/RANGE
1127        32     137 cell 1 - some growth evident
1974       335     153 cell 2


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SC KM

AREA/AZIMUTH/RANGE
 4Ø7       328     154
 496       338     149
```

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 1 2040   29. 136.
 1 2045   32. 137.
                        292.5     92.9       0.00      0.000
 2 2040 335. 157.
 2 2045 335. 153.
                        335.0     51.5       0.00      0.000
 0     0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2100 2200   200   VIC     1     2     0     0     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
157   2050      0
STOP


 4 VST ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
1180        34    140 cell 1
 353        61    188 cell 3 - new
 304       310    163 ----------- {no assignment, wait to see if cell
1884       336    147 cell 2      {will be retained in next PPI


 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 943       335    144

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDCS/    STDTM
 1 2050  34. 140.
                        283.1     78.7      14.36      0.182
 2 2050 336. 148.
                        319.0     58.2      17.90      0.098
 0     0    0.    0.
```

```
COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2105 2205  200  VIC    1    2    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
157  2055      0
STOP


 3 VST ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
1225         36    145 cell 1
 388         61    188 cell 3
2509        324    147 ———— {no assignment as several small cells in line
                             merged, may be result of radar power fluctuation

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 895        336   140

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/   STDTM
 1 2055   36. 144.
                          276.9    75.9    16.73    0.162
 3 2050   61. 188.
 3 2055   61. 188.
                          360.0     0.0     0.00    0.000
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2110 2210  200  VIC    1    3    2    0    0    0    0    0    0
```

```
COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
157  2100      0
STOP


 5 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1077        38    146 cell 1
 340        61    189 cell 3
 357       298    194 cell 4
 561       310    155 cell 6
1656       335    136 cell 2 - centroid position consistent with last cell 2
                                position

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 954       335    133

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/    STDTM
 1 2100  38. 146.
                           277.1     73.1     15.58     0.159
 2 2100 335. 136.
                           334.2     64.3     23.26     0.102
-3 2055  61. 188.
 3 2100  61. 189.
                           241.0      6.1      0.00     0.000
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2115 2215  200  VIC     1    2    3    0    0    0    0    0    0
```

```
COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
157  2105     0
STOP


 6 VST ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 762        39    156) {cell 1 split, wait to see if split remains before making
 252        45    122} (new assignment
 432        60    187cell 3
 600       297    192cell 4 - rapid growth but centroid position consistent
 586       308    152cell 6
1946       336    132cell 2 - growth evident, but centroid position is
                             consistent

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
1087       333    127

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/   STDTM
 2 2105 336. 132.
                        331.8    62.8    24.05    0.142
 3 2105  60. 187.
                        137.5    11.7    22.61    2.883
 4 2100 298. 194.
 6 2100 310. 155.
 4 2105 297. 192.
                        356.8    49.0     0.00    0.000
 6 2105 308. 152.
                          9.8    76.7     0.00    0.000
 0    0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2120 2220  200  VIC    2    3    4    6    0    0    0    0    0
```

```
COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
157  2110      0
STOP


 4 VST ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 879       40    162 no assignment, still not convinced echo 1 won't reappear
 531       59    187 cell 3
 772      296    188 cell 4
1854      332    124 cell 2


 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 726      337    123

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/   STDTM
 3 2110   59. 187.
                          138.9    19.7    20.00    2.746
 4 2110 296. 188.
                          345.0    55.0    12.69    0.110
 2 2110 333. 124.
                          339.1    66.1    40.99    0.230
 0    0   0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2125 2225  200  VIC    1    2    3    4    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
157  2115      0
STOP
```

```
 4 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1060          44     162 cell 1 { area is consistent with last cell 1 area and is
                                   only one in the area, rapid movement is indicated
 497          61     188 cell 3
 815         295     184 cell 4
1868         333     118 cell 2     (cell 6 and smaller part of cell 1 split
                                     dropped)

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 797         337     117

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDCS/    STDTM
 1 2115   44. 162.
                         272.1     79.2      15.85     0.171
 3 2115   61. 188.
                         135.5      7.1      17.95     3.333
 4 2115 295. 184.
                         340.6     57.4      12.34     0.109
 2 2115 333. 118.
                         341.2     68.1      38.06     0.215
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2130 2230   200   VIC     1     3     4     2     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
157  2120       0
STOP
```

```
 5 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1236        48    160 cell 1
 452        60    189 cell 3
 674       295    178 cell 4
 323       305    131 cell 5 - possibly old cell 6, but just as easy to reassign
1699       334    115 cell 2 - some area decrease, but centroid position
                              consistent

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 608       334    107

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/   STDTM
 1 2120   48. 160.
                     277.9     80.7     44.36    0.159
 3 2120   60. 189.
                     155.2      6.2     18.65    3.435
 4 2120 295. 178.
                     329.4     57.6     25.53    0.112
 2 2120 334. 115.
                     340.5     66.6     37.05    0.274
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2135 2235  200  VIC    1    3    4    2    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
157  2125     0
STOP
```

```
 6 VST ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 377        13    189 cell 7 - new
1421        50    165 cell 1 - growth trend indicated                 consistent
 267        60    191 cell 3 - large area decrease, but centroid position/
 908       296    166 cell 4} rapid growth observed in both cells, but
 668       305    126 cell 5} centroid positions consistent
1639       332    105 cell 2

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
 637       336    104

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/   STDTM
 5 2120 305. 131.
 1 2125  50. 165.
                      279.9     82.1     41.50    0.155
 3 2125  60. 191.
                      184.5      6.5     19.48    3.190
 4 2125 296. 166.
                      312.9     66.7     50.69    0.313
 5 2125 305. 126.
                      305.0     61.0      0.00    0.000
 2 2125 332. 105.
                      341.5     69.1     36.33    0.389
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2140 2240  200  VIC    1    3    4    5    2    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
157  2130     0
STOP
```

```
 5 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
 515        12     187 cell 7 - rapid growth from previous PPI
1376        5Ø     173 cell 1 - growth trend reversing
 935       295     163 cell 4
 644       3Ø4     122 cell 5
1732       332     1Ø1 cell 2    (cell 3 dropped by program)


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
 26Ø        57    156
 624       333     93

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDCS/   STDTM
 7 2125   13.  189.
 7 213Ø   12.  187.
                         71.1      46.1      Ø.ØØ     Ø.ØØØ
 1 213Ø   5Ø.  173.
                        278.3      81.8     46.15     Ø.167
 4 213Ø  295.  163.
                        31Ø.Ø      68.5     47.67     Ø.316
 5 213Ø  3Ø4.  122.
                        318.3      55.8     14.75     Ø.121
 2 213Ø  332.  1Ø1.
                        341.7      69.5     34.56     Ø.383
 Ø    Ø    Ø.    Ø.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2145 2245  4ØØ  STA   7   1   4   5   2   Ø   Ø   Ø   Ø

COMMAND
BYE
```

APPENDIX B

Annotated Command Structure, June 16, 1975

```
COMMAND
TWC
HHMM
2400

COMMAND
GCD
20

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1830      0


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1795       280    188
```
cell 1 - new {will track VST cells this run

```
 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1330       281    189
```
ignore SEV cells imbedded in the VST cells above

```
DAY/ TIME/ TILT
167  1835      0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2221       279    186
```
cell 1

```
 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1744       279    186
```

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 1 1830 280. 188.
 1 1835 279. 186.
                           338.0    45.9      0.00      0.000

 0     0     0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1835 1935   200   VIC     1     0     0     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1840       0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2648       278    183 cell 1 - growth due to squall line entering PPI


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1429       269    188
 480       293    185

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 1 1840 278. 183.
                           331.3    49.3      6.59      0.070

 0     0     2.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1840 1940   200   VIC     1     0     0     0     0     0     0     0
```

```
COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
167  1845      0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
3067       279    179
```
cell 1 - line still growing

```
 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1661       270    181

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDDS/   STDTM
 1 1845 279, 179,
                                302.5    39.2    31.11    0.516
 0     0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1845 1945  200  VIC     1     0     0     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
167  1850      0
STOP
```

```
 2 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2863      276    174 cell 1           (cell split on north end of line, will
 265      301    186 no assignment    wait to see if small cell is retained)

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1636      268    179

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STDIM
 1 1850 276. 174.
                               314.0    52.1     43.65    0.843
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1850 1950  240  VIC    1    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
167  1855     0
STOP

 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2675      273    171 cell 1 - area decreasing, small cell dropped

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1362      266    172

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STDIM
 1 1855 273. 171.
                               324.0    63.3     46.94    0.845
 0    0    0.   0.
```

```
COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1855 1955  200  VIC     1    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
167  1900      0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2505       271    165 cell 1 - area still decreasing, centroid position
                                                          consistent

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1274       266    167

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDDS/   STDTH
 1 1900 271. 165.
                            325.4    71.5    43.74    0.812
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1900 2000  200  VIC     1    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
167  1905      0
```

```
 2 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
2238        262    17Ø cell 2 - new {shift in centroid position significant
 36Ø        287    151 cell 3 - new {with this split, redefine echoes

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
1449        263    166

DAY/ TIME/ TILT
167  191Ø      Ø
STOP

 2 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
238Ø        261    167 cell 2 - area and centroid position consistent
 262        285    142 cell 3 - (obvious from PPI same cell as above
                                 rapid motion indicated)

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
1626        261    163

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCIM
 2 19Ø5 262. 17Ø.
 2 191Ø 261. 167.
                        3Ø5.9    55.2     Ø.ØØ     Ø.ØØØ
 3 19Ø5 287. 151.
 3 191Ø 285. 142.
                        315.6   135.9     Ø.ØØ     Ø.ØØØ
ECHO SPEED GREATER THAN 12Ø KM/HR, CHECK THIS CB.
 Ø    Ø   2.   Ø.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
191Ø 2Ø1Ø  2ØØ  VIC    2    3    Ø    Ø    Ø    Ø    Ø    Ø
```

```
COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1915      0
STOP


 2 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2431       261    159 cell 2
 364       287    133 cell 3 - area lost in previous PPI regained


 1 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
1480       261    156

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCFM
 2 1915 261. 159.
                             276.1    69.7     39.15     0.134
 3 1915 287. 133.
                             287.0   110.4     59.72     0.299
 0    0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1915 2015  200  VIC    2    3    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1920      0
STOP
```

1 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
2792 264 146 *cell 1 - (cells 2 and 3 merged, extrapolated position for old cell 1 appears reasonable)*

2 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
574 254 169
591 265 136

COMMAND
ENT
N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/ STDDS/ STDIM
1 192Ø 264. 146.
321.3 77.7 41.41 Ø.761
Ø Ø Ø. Ø.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
192Ø 2Ø2Ø 2ØØ VIC 1 Ø Ø Ø Ø Ø Ø Ø

COMMAND
ACC

AREA/INTENSITY
25Ø 4

DAY/ TIME/ TILT
167 1925 Ø
STOP

1 VST ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
2757 263 14Ø *cell 1*

2 SEV ECHOES FOUND WITH AREA GREATER THAN 25Ø SQ KM

AREA/AZIMUTH/RANGE
518 253 166
435 272 126

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STCDS/    STCTM
 1 1925 263. 140.
                                318.7    78.4     41.81     0.720
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1925 2025  200  VIC    1    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250    4

DAY/ TIME/ TILT
167  1930     0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2560      263    132
```
cell 1 - area starting to decrease

```
 2 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 555      252    155
 442      269    119

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STCDS/    STCTM
 1 1930 263. 132.
                                315.3    77.8     46.93     0.690
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1930 2030  200  VIC    1    0    0    0    0    0    0    0
```

```
COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1935      0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2254       260   126 cell 1 - area decreasing rapidly


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 522       251   150
 525       268   111

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDDS/   STDTM
 1 1935 260. 126.
                           313.3    78.7    44.85    0.668
 0     0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1935 2035  200  VIC    1    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1940      0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
2390       258   120 cell 1
```

```
 2 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 476        251    146
 614        267    103

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 1 1940 258. 120.
                               311.7    79.3     43.72     0.640
 0      0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1940 2040  200  VIC     1     0     0     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
 250     4

DAY/ TIME/ TILT
167  1945      0
STOP


 1 VST ECHOES FOUND WITH AREA GREATER THAN 250 SC KM

AREA/AZIMUTH/RANGE
2246       259   111 cell 1


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 250 SQ KM

AREA/AZIMUTH/RANGE
 417        249    138
 367        267     95

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 1 1945 259. 111.
                               309.0    79.1     50.48     0.626
 0      0    0.    0.
```

```
COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1945 2045   200   VIC      1    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
1000     3

DAY/ TIME/ TILT
167   1946       0
```
(cell 1 broke into several cores after this time; a larger area at a lower intensity was used after this time)

```
 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
9510        354    249
4848        263    115
```
} this data taken at long range, no assignment made

```
 1 VST ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
3962        345    246

DAY/ TIME/ TILT
167   1950       0


 1 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4745        263    110
```
cell 4 - new

```
DAY/ TIME/ TILT
167   1955       0
STOP


 1 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4743        264    108
```
cell 4 - indicated motion unusually slow

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCTM
 4 1950 263. 110.
 4 1955 264. 108.
                                 219.9    36.2      0.00     0.000
 0     0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1955 2055  200  VIC     4     0     0     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
1000     3

DAY/ TIME/ TILT
167  2000      0
STOP


 1 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4849       267      97 cell 4 - (centroid position change very large,
                                 echo seems unstable)
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCTM
 4 2000 267.  97.
                                 235.9    91.2     28.38     1.627
 0     0    0.    0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2000 2100  200  VIC     4     0     0     0     0     0     0     0

COMMAND
ACC

AREA/INTENSITY
1000     3

DAY/ TIME/ TILT
167  2005      0
```

```
 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4345      263      82 cell 5 - new {significant area and centroid position/change
1368      294     155 no assignment - large patch of stratiform rain

DAY/ TIME/ TILT
167  2010     0
STOP


 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4319      263      74 cell 5 - area and centroid position consistent
1320      295     155 no assignment - little motion from previous PPI

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCTM
 5 2005 263.  82.
 5 2010 263.  74.
                         263.0  105.0     0.00     0.000
 0    0   2.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2010 2110  200  VIC    5    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
1000    3

DAY/ TIME/ TILT
167  2015     0
STOP


 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4186      263      64 cell 5 - rapid motion indicated
1434      296     153 no assignment - see above
```

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STCDS/    STCTM
 5 2015 263.  64.
                              263.0  110.4      0.01      0.082
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2015 2115  200  VIC    5    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
1000    3

DAY/ TIME/ TILT
167  2020     0


 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
5162       285      51 cell 6 - new} growth on north end of line caused
1543       296     145 no assignment  significant shift in centroid and area

 1 VST ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
1250       240      82

DAY/ TIME/ TILT
167  2025      0
STOP

 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
5203       284      46 cell 6 - area and centroid position consistent
1442       297     148 no assignment

 1 VST ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
1247       238      77
```

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 6 2020 285.  51.
 6 2025 284.  46.
                               294.1    66.6     0.00     0.000
 0    0   0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2025 2125  200  VIC    6    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
1000    3

DAY/ TIME/ TILT
167  2030     0
STOP


 2 STR ECHOES FOUND WITH AREA GREATER THAN1000 SQ KM

AREA/AZIMUTH/RANGE
4870      287     41 cell 6 - some decrease in area, centroid position
1778      300    145 no assignment                          consistent

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STDDS/    STDTM
 6 2030 287.  41.
                               276.9    62.1    20.79     0.099
 0    0   0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
2030 2130  200  VIC    6    0    0    0    0    0    0    0

COMMAND
BYE
```

APPENDIX C

Annotated Command Structure, November 2, 1974

```
COMMAND
TWC
HHMM
2400

COMMAND
GCD
20

COMMAND
ACC

AREA/INTENSITY
 150     4

DAY/ TIME/ TILT
306  1225       0


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 154         251       76 cell 1 - new
 540         311       95 cell 2 - new

DAY/ TIME/ TILT
306  1228       0


 3 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 219         250       75 cell 1
 189         304       95 cell 3 - new    } Split of cell 2, skip 4 in sequence,
 322         321       94 no assignment   }    may use later

DAY/ TIME/ TILT
306  1230       0
STOP


 4 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 225         251       74 cell 1
 179         306       95 cell 3
 337         321       94 no assignment (no motion from previous time)
 222         349      126 cell 5 - new
```

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STCCS/    STCIM
 1 1225 251.  76.
 1 1228 250.  75.
                          303.3    33.1      0.00     0.000
 1 1230 251.  74.
                          256.0    23.8     27.41     0.803
 3 1228 304.  95.
 3 1230 306.  95.
                          215.0    98.8      0.00     0.000
 0    0   0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1230 1330  200  VIC    1    3    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 150    4

DAY/ TIME/ TILT
306  1232     0


 4 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 210      249     73cell 1
 194      306     94cell 3
 364      321     93no assignment
 193      350    127cell 5

DAY/ TIME/ TILT
306  1234     0


 3 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 192      249     71cell 1
 550      315     92cell 2  (merge of cell 3 with unassigned cell,
 216      349    127cell 5   centroid position consistent with old cell 2)

DAY/ TIME/ TILT
306  1236     0
STOP
```

2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
198 249 70*cell 1*
558 317 92*cell 2*

COMMAND
ENT

N/ HHMM/ AZM/ RNG/	DIRECTION/	SPEED/	STCDS/	STCTM
1 1232 249. 73.				
	283.1	30.8	43.72	0.755
1 1234 249. 71.				
	278.3	36.6	41.90	0.729
1 1236 249. 70.				
	274.1	37.3	38.72	0.675
5 1230 349. 126.				
5 1232 350. 127.				
	235.1	72.5	0.00	0.000
5 1234 349. 127.				
	168.9	15.0	15.84	1.060
2 1225 311. 95.				
2 1234 315. 92.				
	247.7	47.9	0.00	0.000
2 1236 317. 92.				
	242.8	53.3	20.54	0.502
0 0 0. 0.				

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1236 1336 200 VIC 1 2 5 0 0 0 0 0 0

COMMAND
ACC

AREA/INTENSITY
150 4

DAY/ TIME/ TILT
306 1238 0

3 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
196 250 69*cell 1*
551 319 91*cell 2*
152 351 130*cell 5*

```
DAY/ TIME/ TILT
306  1240     0
STOP


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 216      250    68
 546      320    90

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCTM
 1 1238 250.  69.
                              265.2    35.6     39.77     0.675
 1 1240 250.  68.
                              259.9    34.6     37.31     0.635
 2 1238 319.  91.
                              242.1    59.6     17.93     0.619
 2 1240 320.  90.
                              243.2    61.7     18.14     0.556
 5 1238 351. 130.
                              214.7    40.9     36.72     1.329
 0    0   0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1240 1340  200  VIC    1    2    5    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 150    4

DAY/ TIME/ TILT
306  1242     0


 3 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 194      250    67 cell 1
 159      284    86 no assignment
 581      322    90 cell 2
```

```
DAY/ TIME/ TILT
306  1245     0
STOP


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 170      250     64 cell 1        (several cells merged, may be result of
 944      311     83 cell 6 - new  {increase in intensity or radar power
                                   (fluctuation

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 157      327     90

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDDS/   STDIM
 1 1242 250.  67.
                    256.7      34.0     35.21    0.601
 1 1245 250.  64.
                    254.1      35.8     33.48    0.618
 2 1242 322.  90.
                    242.5      64.9     18.45    0.546
 6 1245 311.  83.
 0    0   0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1245 1345  200  VIC    1    2    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 150    4

DAY/ TIME/ TILT
306  1247     0
```

```
 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 157        251       63 cell 1 }
 863        310       81 cell 6 } area loss in both cells, but centroid positions
                                                            consistent

DAY/ TIME/ TILT
306  1249      0


 3 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 153        252       61 cell 1
 850        313       80 cell 6
 197        353      130 cell 7 - new

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 225        325       84

DAY/ TIME/ TILT
306  1251      0
STOP


 3 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 194        255       60 cell 1 }
 946        312       80 cell 6 } growth evident in both cells
 151        353      132 cell 7

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 257        326       85
```

```
COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/    STCDS/    STDTM
 1 1247 251.  63.
                          250.5     36.4     33.63     0.593

 1 1249 252.  61.
                          246.8     37.8     33.45     0.599

 1 1251 255.  60.
                          240.6     39.0     40.84     0.576

 6 1247 310.  81.
                          346.1     74.1      0.00     0.000

 6 1249 313.  80.
                          268.5     62.2     69.93     0.944

 6 1251 312.  80.
                          271.2     39.4     62.41     1.099

 7 1249 353. 132.
 7 1251 353. 132.
                          180.0      0.0      0.00     0.000

 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1251 1351  200  VIC     1    6    7    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 150    4

DAY/ TIME/ TILT
     1253      0


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 199       256      59 cell 1
 971       314      79 cell 6 growth continuing


 2 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 177       300      77
 267       327      85

DAY/ TIME/ TILT
306  1255      0
STOP
```

2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE

241	259	57 *cell 1*	*both cells growing, cell 1 accelerating*
1023	315	80 *cell 6*	

1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE

471	316	78

COMMAND
ENT

N/	HHMM/	AZM/	RNG/	DIRECTION/	SPEED/	STCDS/	STCTM
1	1253	256.	59.				
				236.1	39.9	39.81	0.555
1	1255	259.	57.				
				231.4	41.9	41.75	0.624
6	1253	314.	79.				
				260.7	43.3	58.90	1.076
6	1255	315.	80.				
				248.2	41.6	57.34	1.015
0	0	0.	0.				

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1255 1355 200 VIC 1 6 0 0 0 0 0 0 0

COMMAND
ACC

AREA/INTENSITY
150 4

DAY/ TIME/ TILT
306 1257 0

2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE

295	260	54 *cell 1*
1019	319	80 *cell 6*

1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE

293	326	80

```
DAY/ TIME/ TILT
306  1259      0


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 260       262     52 cell 1
1000       320     79 cell 6

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 231       327     78

DAY/ TIME/ TILT
306  1300      0
STOP

 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 278       262     51 cell 1
1003       322     80 cell 6

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 239       327     77

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDDS/   STDTM
 1 1257 260.  54.
                      228.9    44.4     40.65    0.677
 1 1259 262.  52.
                      227.1    46.9     39.60    0.685
 1 1300 261.  51.
                      226.7    48.3     42.70    0.680
 6 1257 319.  80.
                      237.8    54.6     57.82    1.402
 6 1259 320.  79.
                      236.7    59.5     54.73    1.313
 6 1300 322.  80.
                      234.2    65.0     57.53    1.359
 0    0   0.   0.
```

```
COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1300 1400  200  VIC    1    6    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 150     4

DAY/ TIME/ TILT
306  1302      0


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SC KM

AREA/AZIMUTH/RANGE
 278       267     51 cell 1
 993       324     81 cell 6

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SC KM

AREA/AZIMUTH/RANGE
 207       329     77

DAY/ TIME/ TILT
306  1304      0


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SC KM

AREA/AZIMUTH/RANGE
 266       269     50 cell 1
1048       326     82 cell 6

 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SC KM

AREA/AZIMUTH/RANGE
 202       331     78

DAY/ TIME/ TILT
306  1306      0
STOP
```

```
 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 270        270      49 cell 1
1072        327      81 cell 6


 1 SEV ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 205        332      79

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STDDS/   STDTM
 1 1302 267.  51.
                      224.3      50.2     50.80    0.701
 1 1304 269.  50.
                      222.3      51.8     49.67    0.685
 1 1306 270.  49.
                      221.0      52.8     48.48    0.670
 6 1302 324.  81.
                      231.5      69.2     55.49    1.292
 6 1304 326.  82.
                      229.2      72.6     53.43    1.235
 6 1306 327.  81.
                      229.0      73.3     52.15    1.190
 0    0    0.   0.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
1306 1406  200  VIC    1    6    0    0    0    0    0    0    0

COMMAND
ACC

AREA/INTENSITY
 150    4

DAY/ TIME/ TILT
306  1308     0


 2 VST ECHOES FOUND WITH AREA GREATER THAN 150 SQ KM

AREA/AZIMUTH/RANGE
 290       267      47 cell 1
1052       328      81 cell 6
```

```
DAY/ TIME/ TILT
3Ø6  131Ø      Ø
STOP

 2 VST ECHOES FOUND WITH AREA GREATER THAN 15Ø SQ KM

AREA/AZIMUTH/RANGE
 285      27Ø     46cell 1
1ØØ4      328     8Øcell 6

COMMAND
ENT
 N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/   STCDS/   STCTM
 1 13Ø8 267.  47.
                         221.1     52.9     51.53     Ø.71Ø
 1 131Ø 27Ø.  46.
                         22Ø.9     53.2     5Ø.72     Ø.699
 6 13Ø8 328.  81.
                         229.Ø     72.6     5Ø.14     1.149
 6 131Ø 328.  8Ø.
                         229.8     69.8     48.96     1.143
 Ø    Ø    Ø.   Ø.

COMMAND
DIS

BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS
131Ø 141Ø  2ØØ  VIC    1    6    Ø    Ø    Ø    Ø    Ø    Ø    Ø

COMMAND
BYE
```

APPENDIX D

Computer Program Listing for ECHOPRED

```
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(100),MEN,COF(10,4,10),GATE(220),
     *IGD,BDXTM,IHSK(19)
      DIMENSION IPCINT(200),LNSAV(40)
      DIMENSION NCB(10),AX(10),BX(10),AY(10),BY(10),IENC(10)
      DIMENSION STE2(10),SDE2(10)
      DIMENSION SWT(10),SWT2(10),SWX(10),SWY(10),SWTX(10),SWTY(10)
      DIMENSION SW(10),FTIME(10)
      DIMENSION JCIR(50),          KY(100),ALINE(24),IEC(11),SERTM(50)
      DIMENSION SN1(50),SN2(50),SN3(50),SPTM(50),SDIST(50),CP(9)
      DIMENSION JEC(10),AREA(10),STORM(6)
      DIMENSION IECINT(10)
      DIMENSION IKNT(8)
      DIMENSION ELPS(3)
      REAL*8 SW,SWT,SWT2,SWX,SWTX,SWY,SWTY,XT,YT
      INTEGER GTMIN,GTMAX,T0,T1,T2,BDXTM
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IHSK
      DATA CP/'W ','SW','S ','SE','E ','NE','N ','NW','W '/
      DATA QAIR,QBYE,QENT,QDIS,QDEL.QTWC,QPOS,QWHE,QIGN
     */  3HAIR,3HBYE,3HENT,3HDIS,3HDEL,3HTWC,3HPOS,3HWHE,3HIGN  /
      DATA QKEY,QACC,QGCD,QBQC/3HKEY,3HACC,3HGCD,3HBQC/
      DATA STORM/24H LGT MOD STR VST SEV EXT/
      FADIR(X,Y)=RTD*ATAN2(Y,X)+180.
      HOUR(K)=FLOAT(K/100)+FLOAT(MOD(K,100))/60.
      JHHMM(T)=T*60.+40*IFIX(T)
 1107 FORMAT(2I5,2F5.0)
 1108 FORMAT(1X,I2,I5,2F5.0)
 1706 FORMAT(11I5)
 6706 FORMAT(1X,11I5)
      MXNCE=10
      MEN=100
      MXEP1=MXNCE+1
      RTD=57.2957795
      ALN2=0.6931
      DTR=0.0174532925
      D4BP=4.0/3.1415927
C   READ STATION NAMES ONTO DISK
      REWIND 2
 1731 READ(5,1732)TN1,TN2,TN3,XA,YA
 1732 FORMAT(3A4,3X,2F8.2)
      IF(TN1.EQ.4HTAF )GO TO 1733
CONVERT NM TO KM FOR AIRPORTS  AND STORE ON DISK
      XA=XA*1.852
      YA=YA*1.852
      WRITE(2,1732)TN1,TN2,TN3,XA,YA
      GO TO 1731
 1733 END FILE 2
C...ENTER OVERLAYS ONTO DISK
      REWIND 3
      DO 1790 I=1,2
 1786 READ(5,1787)XB(1),YB(1),XE(1).YE(1)
 1787 FORMAT(7F10.4)
      IF(XB(1).EQ.999.)GO TO 1788
      L=1
      CALL SETLIN(L)
      WRITE(3,1787)XB(1),YB(1),XE(1),YE(1),PHIB(1),PHIE(1),SL(1)
      IF(L.EQ.2)WRITE(3,1787)XB(2),YB(2),XE(2),YE(2),PHIB(2),PHIE(2),SL(
     *2)
      GO TO 1786
 1788 END FILE 3
 1790 CONTINUE
C       DEFAULT TIME WEIGHT CONSTANT IS 30 MINUTES.
      TWC=-ALN2*0.5
C.....DEFAULT GROUND CLUTTER DISTANCE FOR ECHO CONTOURING IS 20 KM
      IGD=20
C....IF NO TIME IS AVAILABLE FROM BENDIX DISPLAY BDXTM = 0.
      BDXTM=0.
C       READ COMMAND
      DO 1020 I=1,10
      JEC(I)=0
```

```
      DO 1Ø2Ø J=1,4
      DO 1Ø2Ø K=1,1Ø
 1Ø2Ø COF(I,J,K)=Ø.
      DO 1Ø1Ø I=1,MEN
 1Ø1Ø MAP(I)=Ø
      I=1
 1Ø35 DO 1Ø4Ø I=I,MXNCE
      IENC(I)=Ø
 1Ø4Ø NOB(I)=Ø
 21ØØ WRITE(6,21Ø1)
 21Ø1 FORMAT('ØCOMMAND')
C***36Ø DEPENDENT
      READ(5Ø,21Ø5)CMD
C*******
      WRITE(6,21Ø6)CMD
 21Ø6 FORMAT(1X,24A3)
 21Ø5 FORMAT(24A3)
      IF(CMD .EQ. CENT)GO TO 11ØØ
      IF(CMD .EQ. QGCD)GO TO 12ØØ
      IF(CMD .EQ. CTWC)GO TO 13ØØ
      IF(CMD .EQ. CBYE)GO TO 14ØØ
      IF(CMD .EQ. CIGN)GO TO 15ØØ
      IF(CMD .EQ. QDEL)GO TO 16ØØ
      IF(CMD .EQ. CAIR)GO TO 17ØØ
      IF(CMD .EQ. CDIS) GO TO 18ØØ
      IF(CMD .EQ. CPOS)GO TO 19ØØ
      IF(CMD .EQ. QACC)GO TO 2ØØØ
      IF(CMD .EQ. CWHE)GO TO 33ØØ
      IF(CMD .EQ. CBQC)GO TO 5ØØØ
      WRITE(6,211Ø)CMD
 211Ø FORMAT(1X,A3,' INVALID.')
      GO TO 21ØØ
C
C        TIME WEIGHT CONSTANT
C        ENTER ECHO OBSERVATION
 11ØØ WRITE(6,11Ø1)
 11Ø1 FORMAT('   N/ HHMM/ AZM/ RNG/ DIRECTION/ SPEED/     STDDS/     STDTM')
      DO 11Ø2 I=1,MXNCE
 11Ø2 JEC(I)=Ø
C        READ ECHO OBSERVATION
 11Ø5 JE=Ø
C***36Ø DEPENDENT
      READ(5Ø,11Ø7)JE,JTM,EAZM,ERNG
C*******
      WRITE(6,11Ø8)JE,JTM,EAZM,ERNG
      J=IABS(JE)
      IF(J .EQ. Ø)GO TO 21ØØ
C        PERFORM INPUT VALIDITY CHECK.
      IF(J .GT. MEN)GO TO 116Ø
      IF(MOD(JTM,1ØØ) .GE. 6Ø)GO TO 1165
      IF(EAZM.GT.36Ø)GO TO 117Ø
C        COMPUTE TIME IN HOURS, X AND Y COORDINATES.
      ETIM=HOUR(JTM)
      AZM=EAZM*DTR
      XT=DCOS(AZM)*ERNG
      YT=DSIN(AZM)*ERNG
C        CHECK FOR NEW ECHO.
      L=MAP(J)
      IF(L . GT . Ø) GO TO 113Ø
      IF(JE .LT. Ø)GO TO 1135
C       NEW ECHO. ALLOCATE.
      DO 1115 L=1,MXNCE
      IF(IENC(L) . EQ. Ø) GO TO 1125
 1115 CONTINUE
C       ALL WORKING ECHOS USED.
      WRITE(6,112Ø)IENC
C***36Ø DEPENDENT
 112Ø FORMAT('UNABLE TO ACCOMODATE NEW ECHO.'
     * ,' DELETE ONE OF THE FOLLOWING'/1ØI4)
C*******
      GO TO 21ØØ
C       START NEW ECHO WITH INDEX L
 1125 NOB(L)=1
      IENC(L)=J
      MAP(J)=L
      SDE2(L)=Ø.
      STE2(L)=Ø.
      SW(L)=1.Ø
      SWT(L)=ETIM
```

```
      SWT2(L)=ETIM**2
      SWX(L)=XT
      SWTX(L)=XT*ETIM
      SWY(L)=YT
      SWTY(L)=ETIM*YT
      FTIME(L)=ETIM
 1129 GO TO 1105
 1130 IF(FTIME(L).GT.ETIM)ETIM=ETIM+24.
C       COMPUTE WEIGHT FACTOR
      W=EXP(TWC*(ETIM-FTIME(L)))
C        TEST FOR OBSERVATION DELETION.
      IF (JE.GT.0) GO TO 1140
C       DELETE PREVIOUS OBSERVATION
      IF(ETIM .LE. FTIME(L))GO TO 1135
 1133 WRITE(6,1134)
 1134 FORMAT(' YOU CANT DELETE SOMETHING THATS NOT THERE')
      GO TO 2100
 1135 NOB(L)= NOB(L)-1
      IF(NOB(L) .LE. 0)GO TO 1137
      SW(L)=SW(L)-W
      SWT(L)=SWT(L)-W*ETIM
      SWT2(L)=SWT2(L)-W*ETIM**2
      SWX(L)=SWX(L)-W*XT
      SWY(L)=SWY(L)-W*YT
      SWTX(L)=SWTX(L)-W*ETIM*XT
      SWTY(L)=SWTY(L)-W*ETIM*YT
      GO TO 1105
 1137 IENC(L)=0
      MAP(J)=0
      GO TO 1105
C       ADD NEW OBSERVATION
 1140 DT=ABS(ETIM-FTIME(L))
      IF (DT .EQ. 0.)GO TO 1175
      IF(NOB(L) .LT. 2)GO TO 1145
C       COMPUTE ERRORS
      PTIME=(AX(L)*(XT-BX(L))+ AY(L)*(YT-BY(L)))/(AX(L)**2+AY(L)**2)
      PX=AX(L)*PTIME+BX(L)
      PY=AY(L)*PTIME+BY(L)
      ERDST=SQRT((PX-XT)**2+(PY-YT)**2)
      ERTIM=ABS(ETIM-PTIME)
      RERDS=ERDST/DT
      RERTM=ERTIM/DT
      STE2(L)= STE2(L)+RERTM**2
      SDE2(L)=SDE2(L)+RERDS**2
 1145 NOB(L)=NOB(L)+1
      SW(L)=W*SW(L) + 1.0
      SWT(L)=W*SWT(L) + ETIM
      SWT2(L)=W*SWT2(L) + ETIM * ETIM
      SWX (L)=W*SWX(L) + XT
      SWY(L)=W*SWY(L) + YT
      SWTX(L)=W*SWTX(L) + ETIM*XT
      SWTY(L)=W*SWTY(L) + ETIM*YT
      FTIME(L)=AMAX1(FTIME(L), ETIM)
C       COMPUTE NEW APPROXIMATING POLY AND SPEED/DIR.
      DEN=SW(L)*SWT2(L)-SWT(L)**2
      VV=(SW(L)*SWTX(L)-SWT(L)*SWX(L))/DEN
      UU=(SW(L)*SWTY(L)-SWT(L)*SWY(L))/DEN
      AX(L)=VV
      AY(L)=UU
      BX(L)=XT-VV*ETIM
      BY(L)=YT-UU*ETIM
      ADIR=FADIR(VV,UU)
 1149 SPD=SQRT(UU**2+VV**2)
      ANOE=NOB(L)
      STDDS=SQRT(SDE2(L)/ANOE)
      STDTM=SQRT(STE2(L)/ANOE)
      EDPH=AMAX1(STDDS,10.)
      BT24=HOUR(BDXTM)
      IF(ETIM.GT.BT24)BT24=BT24+24.
      IF(ETIM.NE.BT24)GO TO 1182
      DO 1180 J1=1,MXNOE
      A=COF(1,1,J1)
      B=COF(1,3,J1)
      ASUB=SQRT((A-YT)**2+(B-XT)**2)
      IF(J1.EQ.1)GO TO 1179
      IF(ASUB-AMIN)1179,1180,1180
 1179 AMIN=ASUB
      JEC(L)=J1
 1180 CONTINUE
```

```
      IF(AMIN.LE.ECPH)GO TO 1182
      WRITE(6,1181)
 1181 FORMAT('0CHECK CENTROID OF THIS ECHO. THIS OBSERVATION DELETED')
      GO TO 1135
 1182 WRITE(6,1150)ADIR,SPD,STDDS,STDTM
 1150 FORMAT(19X,F10.1,F7.1,F9.2,F9.3)
      IF(SPD.GT.120.)GO TO 1185
      GO TO 1105
C       INPUT ERRORS
 1160 WRITE(6,1161)
 1161 FORMAT(' ECHO NO. TOO LARGE')
      GO TO 2100
 1165 WRITE(6,1166)
 1166 FORMAT(' SOMETHING SCREWY ABOUT THAT TIME')
      GO TO 2100
 1170 WRITE(6,1171)
 1171 FORMAT(' AZIMUTH DOES NOT COMPUTE')
      GO TO 2100
 1175 WRITE(6,1176)
 1176 FORMAT(' PREVIOUS ECHO AT SAME TIME.  THIS OBS IGNORED')
      GO TO 1105
 1185 WRITE(6,1186)
 1186 FORMAT(' ECHO SPEED GREATER THAN 120 KM/HR, CHECK THIS OB.')
      GO TO 1105
C...SET GROUND CLUTTER DISTANCE FOR CONTOURING
 1200 READ(50,1205)IGD
 1205 FORMAT(I3)
      WRITE(6,1205)IGD
      GO TO 2100
 1300 WRITE(6,1305)
 1305 FORMAT(' HHMM')
C***360 DEPENDENT
      READ(50,1107)ITWC
      WRITE(6,1706)ITWC
      TWC=-ALN2/HOUR(ITWC)
      GO TO 2100
C
C       BYE.  STOP.
 1400 CALL TPREW(10)
      CALL TPWTM(11)
      CALL TPREW(11)
      STOP
C
C        IGNORE TEXT.
C***360 DEPENDENT
 1500 READ(50,2105)ALINE
      WRITE(6,2106)ALINE
      IF(ALINE(1) .EQ. QKEY)GO TO 2100
      GO TO 1500
C
C        DELETE AN ECHO.
 1600 DO 1605 I=1,MXEP1
 1605 IEC(I)=0
      WRITE(6,1606)
 1606 FORMAT(' WHICH ECHOS')
C***360 DEPENDENT
      READ(50,1706)IEC
C***360 DEPENDENT
      WRITE(6,6706)IEC
      DO 1610 I=1,MXEP1
      K=IEC(I)
      IF(K.LE.0.OR.K.GT.MEN)GO TO 1610
      L=MAP(K)
      IF(L .LE. 0)GO TO 1610
      IENO(L)=0
      MAP(K)=0
 1610 CONTINUE
 1615 K=0
      DO 1620 I=1,MXNCE
      IF(IENO(I) .EQ. 0)GO TO 1620
      K=K+1
      IEC(K)=IENO(I)
 1620 CONTINUE
      IF(K .EQ. 0)GO TO 1630
      WRITE(6,1625)(IEC(I),I=1,K)
 1625 FORMAT('** ACTIVE ECHOS ',10I4)
      GO TO 2100
 1630 WRITE(6,1635)
 1635 FORMAT('** NO ACTIVE ECHOS')
```

```
      GOTC 2103
C
C        PRECICT ECHO PATH CVER AIRPORTS
 1700 WRITE(6,1703)
 1703 FORMAT(' BTIME/ ETIME/ STD DEV/ ECHO NO.S')
      DO 1705 I=1,MXNCE
 1705 IEC(I)=0
C***360 DEPENDENT
      READ(50,1707)JTB,JTE,SDD,IEC
C*******
C**   FORMAT 1706 HAS MULTIPLE REFS.
 1707 FORMAT(2I5,F5.0,11I5)
 6707 FORMAT(1X,2I5,F5.0,11I5)
      WRITE(6,6707)JTB,JTE,SDD,IEC
      BT24=HOUR(JTB)
      ET24=HOUR(JTE)
      DO 1790 JE=1,MXNCE
      J=IEC(JE)
      L=LEGEN(J)
      IF(L .LE. 0)GO TO 2100
      WRITE(6,1708)J
 1708 FORMAT('0ECHO'I4)
C        COMPUTE BOUNDARY OF BOX.
      NOBL=NCB(L)
      ANCE=NCBL
      RTM=FTIME(L)
      IF(BT24.GE.RTM)GO TO 4000
      BTIM=BT24+24.
      ETIM=ET24+24.
      GO TO 4010
 4000 BTIM=BT24
      ETIM=ET24
      IF(ETIM.LT.BTIM)ETIM=ETIM+24.
 4010 EDPH=AMAX1(SDD*SQRT(SDE2(L)/ANOE),10.)
      ETPH=AMAX1(SQRT(STE2(L)/ANOE),0.1)
      AXL=AX(L)
      BXL=BX(L)
      AYL=AY(L)
      BYL=BY(L)
      RSSQ=1.0/(AXL*AXL+AYL*AYL)
      EC=SQRT(RSSQ)*EDPH
      WB=ABS((BTIM-RTM)*AXL*EC)
      WE=ABS((ETIM-RTM)*AXL*EC)
      PB=AXL*BTIM+BXL
      PE=AXL*ETIM+BXL
      PX0=AMIN1(PB-WB,PE-WE)
      PX1=AMAX1(PB+WB,PE+WE)
      WB=ABS((BTIM-RTM)*AYL*EC)
      WE=ABS((ETIM-RTM)*AYL*EC)
      PB=AYL*BTIM+BYL
      PE=AYL*ETIM+BYL
      PY0=AMIN1(PB-WB,PE-WE)
      PY1=AMAX1(PB+WB,PE+WE)
      NT=0
      NCK=0
C
C        READ TABLE OF TOWNS AND REPORT THOSE TOWNS IN PATH OF ECHO
C
 1710 WRITE(6,1713)
 1713 FORMAT(' TIME  AIRPORT          DIST      FTIM LTIM')
      REWIND 2
 1730 READ(2,1732,END=1745)TN1,TN2,TN3,XA,YA
C*******
C
C        CHECK FOR LOCATION IN BOXED AREA.
      NCK=NCK+1
      IF(XA .LT. PX0 .OR. XA .GT. PX1)GO TO 1742
      IF(YA .LT. PY0 .OR. YA .GT. PY1)GO TO 1742
C        COMPUTE ERRORS
      PTIME=(AXL*(XA-BXL)+AYL*(YA-BYL))*RSSQ
      PX=AXL*PTIME+BXL
      PY=AYL*PTIME+BYL
      DIST=SQRT((PX-XA)**2+(PY-YA)**2)
      DT=ABS(RTM-PTIME)
 1737 IF(DIST .GT. EDPH*DT)GO TO 1743
      IF(PTIME .LT. BTIM .OR. PTIME .GT. ETIM)GO TO 1742
 1738 NT=NT+1
      SN1(NT)=TN1
      SN2(NT)=TN2
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```
      SN3(NT)=TN3
      SDIST(NT)=DIST
      JDIR(NT)=C4BP*ATAN2(PX-XA,PY-YA)+5.5
      SPTM(NT)=PTIME
      SERTM(NT)=DT*ETPH
 1740 GO TC 1730
C       ALL STATICNS/AIRPORTS CHECKED.
 1745 IF(NT.GT.0)GC TC 1750
      WRITE(6,1146)
 1146 FORMAT(' NC ENCCUNTERS PREDICTED')
      GO TC 1780
C       SCRT STATICNS BY ENCOUNTER TIME.
 1750 CALL ISORT(SPTM,KY,NT)
      DO 1775 I=1,NT
      J=KY(I)
      JPTM=JHHMM(SPTM(J))
      JT1=JHHMM(SPTM(J)-SERTM(J))
      JT2=JHHMM(SPTM(J)+SERTM(J))
      K=JDIR(J)
 1765 WRITE(6,1770)JPTM,SN1(J),SN2(J),SN3(J),SDIST(J),CP(K),JT1,JT2
 1770 FORMAT(I5,2X,3A4,F6.1,1X,A2,I6,I3)
 1775 CONTINUE
      WRITE(6,1777)NT
 1777 FORMAT(1H0,I4,' ENCOUNTERS LISTED')
 1780 WRITE(6,1785)
C
C....DISPLAY CCNTOUREC ECHCES WITH WARNING AREAS ON BENDIX SYSTEM
C
 1785 FORMAT(////)
      GO TC 2100
C...FIND BOUNDARY POINTS OF CONE.
COMPUTE LOCATICN CF PCINTS ALONG PATH OF ECHO AT BTIM AND ETIM
 1800 WRITE(6,1805)
 1805 FORMAT(' ?BTIME/ETIME/RANGE/OVERLAY/ECHO NUMBERS')
      READ(50,1810)JTB,JTE,IRNG,OVLY,IEC
 1810 FORMAT(3I5,2X,A3,11I3)
      WRITE(6,1810)JTB,JTE,IRNG,OVLY,IEC
      IGTLENG=IRNG/200
      DO 1809 LINC=1,40
      ISVGT(LINC)=0
      LNSAV(LINC)=0
      GTMAX(LINC)=0
 1809 GTMIN(LINC)=0
      DO 1811 LINC=1,200
      YB(LINC)=0.
      XE(LINC)=0.
      YE(LINC)=0.
      PHIB(LINC)=0.
      PHIE(LINC)=0.
      SL(LINC)=0.
 1811 XB(LINC)=0.
      DO 1850 JE=1,MXNCE
      J=IEC(JE)
      L=LEGEN(J)
      IF(L.LE.0)GC TO 1850
      IF(NCB(L).GE.2)GC TO 1852
      WRITE(6,1853) J
 1853 FORMAT(' YOU CANT PREDICT FROM ONE OB. ECHO',I3,' IGNCRED.')
      GO TC 1850
 1852 IECH=JEC(L)
      IF(IECH.GT.0)GC TO 1848
      DO 1851 I=1,10
      IF(COF(1,1,I).NE.0..CR.COF(1,3,I).NE.0.)GO TO 1851
      IECH=I
      PX=AX(L)*FTIME(L)+BX(L)
      PY=AY(L)*FTIME(L)+BY(L)
      COF(1,3,IECH)=PX
      COF(1,1,IECH)=PY
      COF(2,1,IECH)=10.
      COF(2,4,IECH)=10.
      NHAM(IECH)=2
      SLENG(IECH)=45.
      JEC(L)=IECH
      GO TC 1848
 1851 CONTINUE
      WRITE(6,1849)J
 1849 FORMAT(' NC CCNTCUR FOR ECHO'.I3)
      GO TC 1850
 1848 CALL ECHC(IECH)
```

```
 1850 CONTINUE
      LINE=0
      INT=56
      DO 1816 I=4,9
      GATE(I+10)=IHSK(I+10)
 1816 GATE(I)=IHSK(I)
      GATE(10)=JTB/1000
      GATE(11)=MOD(JTB/100,10)
      GATE(12)=MOD(JTB,100)/10
      GATE(13)=MOD(JTB,10)
      GATE(18)=IGTLENG
      BT24=HCUR(JTB)
      ET24=HCUR(JTE)
      DO 1820 JE=1,MXNCE
      J=IEC(JE)
      L=LEGEN(J)
      IF(L.LE.0)GO TO 1820
      NOBL=NCB(L)
      IF(NOBL.LT.2)GO TO 1820
      IECH=JEC(L)
      ANOE=NOBL
      EDPH=AMAX1(SQRT(SDE2(L)/ANOE),10.)
      RTM=FTIME(L)
      IF(BT24.GE.RTM)GO TO 1814
      BTIM=BT24+24.
      ETIM=ET24+24.
      GO TO 1815
 1814 BTIM=BT24
      ETIM=ET24
      IF(ETIM.LT.BTIM)ETIM=ETIM+24.
 1815 BT=ABS(BTIM-RTM)
      ET=ABS(ETIM-RTM)
      ETPH=AMAX1(SQRT(STE2(L)/ANOE),0.1)
      IF(ETPH.GT.ABS(ET-BT))ETPH=ABS(ET-BT)/2.
      QX1=AY(L)*(BTIM-ETPH)+BY(L)
      QY1=AX(L)*(BTIM-ETPH)+BX(L)
      QX2=AY(L)*(ETIM+ETPH)+BY(L)
      QY2=AX(L)*(ETIM+ETPH)+BX(L)
      XM=(QY2-QY1)/(QX2-QX1)
      CALL ELLIPS(XM,TANW,XK,ELPS,IECH)
      IF(EDPH.GT.XK)EDPH=XK
      RAD=SQRT((EDPH*BT+XK)**2/(TANW*TANW+1.))
      RX1=QX1+RAD
      RX2=QX1-RAD
      RY1=TANW*(RX1-QX1)+QY1
      RY2=TANW*(RX2-QX1)+QY1
      RAD=SQRT((EDPH*ET+XK)**2/(TANW*TANW+1.))
      SX1=QX2+RAD
      SX2=QX2-RAD
      SY1=TANW*(SX1-QX2)+QY2
      SY2=TANW*(SX2-QX2)+QY2
      LINE=LINE+1
      XB(LINE)=RX1
      YB(LINE)=RY1
      XE(LINE)=RX2
      YE(LINE)=RY2
      CALL SETLIN(LINE)
      LINE=LINE+1
      XB(LINE)=RX1
      YB(LINE)=RY1
      XE(LINE)=SX1
      YE(LINE)=SY1
      CALL SETLIN(LINE)
      LINE=LINE+1
      XB(LINE)=SX1
      YB(LINE)=SY1
      XE(LINE)=SX2
      YE(LINE)=SY2
      CALL SETLIN(LINE)
      LINE=LINE+1
      XB(LINE)=RX2
      YB(LINE)=RY2
      XE(LINE)=SX2
      YE(LINE)=SY2
      CALL SETLIN(LINE)
 1820 CONTINUE
      IWARN=LINE
CHECK IF OVERLAY IS TO BE DISPLAYED
      REWIND 3
```

```
      MXNCLN=LINE
      IF(CVLY.EC.3H    )GC TO 1849
      IOVLY=1
      LINE=LINE+1
      IF(CVLY.EC.3HSTA)ICVLY=2
      GO TC(1825,1835),ICVLY
 1825 READ(3,1830,END=1835)XB(LINE)
 1830 FORMAT(7F10.4)
      GO TC 1825
 1835 READ(3,1330,END=1840)XB(LINE).YB(LINE),XE(LINE),YE(LINE),PHIB(LINE
     *),PHIE(LINE),SL(LINE)
      MXNCLN=LINE
      LINE=LINE+1
      GC TC 1835
 1840 CALL LNSCRT(LNCNT,IPCINT,MXNOLN)
      ILNE=0
      DO 3 L=1,LNCNT
      CALL GETLIN(ILNE,L,IPOINT)
      LNSAV(L)=ILNE
 3    CONTINUE
C...START CC LCCP CF AZIMUTH
      DO 66 II=1,360
      IAZ=II-1
CONVERT  TC MATHMATICAL CEGREESP
      IF(IAZ.LE.90)ANGLE=90-IAZ
      IF(IAZ.GT.90)ANGLE=450-IAZ
      ANGLE=ANGLE*CTR
      DO 146 IGT=20,220
      GATE(IGT)=0
 146  CONTINUE
      GATE(1)=IAZ/100
      GATE(2)=MCD(IAZ,100)/10
      GATE(3)=MCD(IAZ,10)
      DO 59 L=1,LNCNT
 58   LINE=IPCINT(LNSAV(L))
      IF(XB(LINE).EQ.999.)CO TO 59
      INT=8
      IF(LINE.LE.IWARN)INT=56
      IPHIB=PHIB(LINE)+.5
      IPHI=PHIE(LINE)+.5
      JAZ=IAZ
      IF(JAZ.LT.IPHIB)GO TC 59
      PHIDFF=ABS(PHIB(LINE)-PHIE(LINE))
      IF(PHICFF.GT.1.AND.PHIDFF.LT.179.)GO TO 99
      IRNG=GTMIN(L)
 75   IF(INT.GT.GATE(IRNG))GATE(IRNG)=INT
      IRNG=IRNG+1
      IF(IRNG.GT.GTMAX(L))GC TO 57
      GC TC 75
 99   IF(ABS(XE(LINE)-XB(LINE)).GE..0001)GO TO 106
      SL(LINE)=999.9999
      RANGE=XE(LINE)/CCS(ANGLE)
      GO TC 107
 106  RANGE=(YB(LINE)-SL(LINE)*XB(LINE))/(SIN(ANGLE)-SL(LINE)*COS(ANGLE)
     *)
 107  RANGE=ABS(RANGE)
      IRNG=RANGE/FLCAT(IGTLENG)+20.
      IF(JAZ.GT.IPHIB.AND.JAZ.LT.IPHI)GO TO 108
      IF(IABS(IRNG-GTMIN(L)).LT.IABS(IRNG-GTMAX(L)))GO TO 109
      IRNG=GTMAX(L)
      GO TC 108
 109  IRNG=GTMIN(L)
 108  IF(IRNG.GT.GTMAX(L))IRNG=GTMAX(L)
      IF(INT.GT.GATE(IRNG))GATE(IRNG)=INT
      IF(ISVGT(L).EQ.0)GC TO 53
      JRNG=ISVGT(L)
 55   IF(IABS(IRNG-JRNG).LE.1)GO TO 53
      IF(IRNG-JRNG)54,59,56
 56   JRNG=JRNG+1
 52   IF(INT.GT.GATE(JRNG))GATE(JRNG)=INT
      GO TC 55
 54   JRNG=JRNG-1
      GO TC 52
 53   ISVGT(L)=IRNG
      IF(GATE(IRNG-1).EQ.0.AND.GATE(IRNG+1).EQ.0)GATE(IRNG-1)=INT
 571  IF(JAZ.LT.IPHI)GC TO 59
 57   CALL GETLIN(ILNE,L,IPOINT)
      LNSAV(L)=ILNE
      GO TC 58
```

```
59    CONTINUE
      INT=16
      DO 1865 JE=1,MXNCE
      J=IEC(JE)
      L=LEGEN(J)
      IF(L.LE.0)GO TO 1865
      IECH=JEC(L)
      IF(IECH.EQ.0)GO TO 1865
      IE=SLENG(IECH)
      DO 1860 I=1,IE
      IF(IECAZ(IECH,I).NE.IAZ)GO TO 1860
      KRNG=IECRNG(IECH,I)
      IF(KRNG.GT.220)STOP MAIN
      IF(INT.GT.GATE(KRNG))GATE(KRNG)=INT
      IF(GATE(KRNG-1).LT.INT)GATE(KRNG-1)=INT
      IF(KRNG.GE.219)GO TO 1860
      IF(GATE(KRNG+1).LT.INT)GATE(KRNG+1)=INT
1860  CONTINUE
1865  CONTINUE
      CALL TPWRIT(11,GATE,220,$500,$501)
60    CONTINUE
      GO TO 2100
500   WRITE(6,104)
104   FORMAT(1H0,23HEND OF TAPE ENCOUNTERED////)
      GO TO 2100
501   WRITE(6,105)
105   FORMAT(1H0,28HERROR IN WRITING ENCOUNTERED////)
      GO TO 2100
C        PREDICT POSITION AT GIVEN TIME
 1900 WRITE(6,1902)
 1902 FORMAT('  ECHO NO/ HHMM')
C***360 DEPENDENT
      READ(50,1707)JE,JTIM
C*******
      WRITE(6,6707)JE,JTIM
      L=LEGEN(JE)
      IF(L .LE. 0)GO TO 270
      GTIM=HOUR(JTIM)
      IF(GTIM.LT.FTIME(L))GTIM=GTIM+24.
      PX=AX(L)*GTIM+BX(L)
      PY=AY(L)*GTIM+BY(L)
      DT=ABS(GTIM-FTIME(L))
      RAD1=DT*SQRT(SDE2(L)/(NOB(L)*(AX(L)**2+AY(L)**2)))
      RAD3=3.*RAD1
      RNG=SQRT(PX**2+PY**2)
      AZM=FADIR(-PX,-PY)
      WRITE(6,1905)AZM,RNG,RAD1,RAD3
 1905 FORMAT('  AZM,RNG ='2F6.1,'    RAD 1SD='F5.1,'    RAD 3SD='F5.1)
      GO TO 2130
 3290 CONTINUE
 270  WRITE(6,271)
  271 FORMAT('  NO ECHO')
      GOT O 2100
C
C...ACCEPT PPI FROM BENDIS DISPLAY
 2000 WRITE(6,2001)
 2001 FORMAT(1H0,'AREA/INTENSITY')
      READ(50,2005)IAREA,INTSW
 2005 FORMAT(2I5)
      WRITE(6,2005)IAREA,INTSW
      INTEN=8*INTSW
C...READ PPI DATA FROM DX
 2010 CALL CONTUR(INTEN,IAREA,AREA,IECINT,IGL)
      READ(50,2015)INTRPT
 2015 FORMAT(A4)
      WRITE(6,2016)INTRPT
 2016 FORMAT(1X,A4)
      IECN=IECNC-1
      IF(IECN.EQ.0)GO TO 2029
      DO 2024 I=INTSW,7
      ICT=0
      DO 2025 IECH=1,IECN
      IF(IECINT(IECH).EQ.I)ICT=ICT+1
 2025 CONTINUE
      IF(ICT.EQ.0)GO TO 2024
      WRITE(6,2027)
 2027 FORMAT(1H0)
      WRITE(6,2012)ICT,STORM(I),IAREA
 2012 FORMAT(I3,A4,' ECHOES FOUND WITH AREA GREATER THAN',I4,' SQ KM'/
```

```
     *' AREA/AZIMUTH/RANGE')
      DO 2020 IECH=1,IECN
      IF(IECINT(IECH).NE.I)GO TO 2020
      X=CCF(1,1,IECH)
      Y=CCF(1,3,IECH)
      R=SQRT(X*X+Y*Y)*FLOAT(IGL)
      CALL ARCTAN(X,Y,AZ)
      IAR=AREA(IECH)+.5
      IR=R+.5
      IAZ=AZ+.5
      WRITE(6,2013)IAR,IAZ,IR
 2013 FORMAT(1X,I4,I8,I6)
 2020 CONTINUE
 2024 CONTINUE
      GO TO 2014
 2009 WRITE(6,2011)STORM(INTSW),IAREA
 2011 FORMAT('0NO',A4,' ECHOES FOUND WITH AREA GREATER THAN',I4,' SQ KM'
     *)
 2014 IF(INTRPT.EQ.4HSTOP)GO TO 2100
      GO TO 2010
C        PREDICT WHEN ECHO WILL BE NEAREST GIVEN POINT.
 3000 WRITE(6,3001)
 3001 FORMAT(' ECHO NO/ AZM/ RNG')
C***360 DEPENDENT
      READ(50,3002)JE,AZM,RNG
 3002 FORMAT(I5,2F5.0)
      WRITE(6,3003)JE,AZM,RNG
 3003 FORMAT(I8,2F5.0)
C******
      L=LEGEN(JE)
      IF(L .LE. 0)GO TO 2090
      AZ=AZM*DTR
      XA=RNG*COS(AZ)
      YA=RNG*SIN(AZ)
      DEN=AX(L)**2+AY(L)**2
      PTIME=(AX(L)*(XA-BX(L))+AY(L)*(YA-BY(L)))/DEN
      DT=ABS(PTIME-FTIME(L))
      SD=STE2(L)/NCB(L)
      IF(NCB(L) .LT. 3)SD=0.5
      ERTM=DT*SD
      T0=JHHMM(PTIME-ERTM)
      T1=JHHMM(PTIME)
      T2=JHHMM(PTIME+ERTM)
      PX=AX(L)*PTIME+BX(L)
      PY=AY(L)*PTIME+BY(L)
      DS=SQRT((PX-XA)**2+(PY-YA)**2)
      SDD=STE2(L)/(NCB(L)*DS)
      WRITE(6,3005)DS,SDD,T1,T0,T2
 3005 FORMAT(1X,F5.1,' MILES(+/-'F4.1,')  AT'I5,'    ('I4,' - 'I4,')')
      GO TO 2100
C
 200  WRITE(6,201)
  201 FORMAT(' IN ERR')
      GOTO 2100
C...QUALITY CONTROL FOR BENDIX
 5000 WRITE(6,5005)
 5005 FORMAT(' PPI CHECK')
      READ(50,5010)ALFA
 5010 FORMAT(A4)
      WRITE(6,5010)ALFA
      WRITE(6,5015)
 5015 FORMAT(' TEST PATTERN')
      READ(50,5010)BETA
      WRITE(6,5010)BETA
      IF(ALFA.NE.4H YES)GO TO 5100
      II=1
 5020 CALL TPREAD(10,GATE,220,LENR,$5080,$5090)
      DO 5025 K=1,19
 5025 IHSK(K)=GATE(K)
      CALL DECODE(IHSK,IAZ,ITLT,ISTC,JUL,ITIME,IDLY,IGL,ITC)
      ISAVTM=ITIME
      JULSAV=JUL
      IF(II.GT.1)GO TO 5035
      WRITE(6,5030)IAZ,ITLT,ISTC,JUL,ITIME,IDLY,IGL,ITC
 5030 FORMAT('   IAZ TILT STC JUL    TIME DLY GL TC'/2I5,2I4,I7,I4,2I3)
C....SUM UP BITS
      DO 5031 I=1,7
 5031 IKNT(I)=0
 5035 DO 5045 K=20,219
```

```
      KNT=GATE(K)/8
      IKNT(KNT)=IKNT(KNT)+1
5045  CONTINUE
      IF(IAZ.NE.359.AND.II.NE.360)GO TO 5055
      WRITE(6,5050)IAZ,II
5050  FORMAT('0LAST AZIMUTH =',I4,' LAST RADIAL =',I4)
      WRITE(6,5060)
5060  FORMAT('0INTENSITY BIT COUNT'/9X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,
     *9X,1H6,9X,1H7)
      WRITE(6,5065)(IKNT(I),I=1,7)
5065  FORMAT(7I10)
      GO TO 5100
5055  CALL TIMDFF(JUL,ITIME,JULSAV,ISAVTM,IDFF,ITFF)
      IF(IABS(ITFF).GT.1.OR.IABS(IDFF).GT.1)WRITE(6,5070)JUL,ITIME
5070  FORMAT('0ERROR IN DATE/TIME, DATE =',I4, ' TIME =',I7)
      IF(IAZ.NE.II-1)WRITE(6,5075)IAZ,II
5075  FORMAT('AZIMUTH =',I4,' RADIAL =',I4)
      II=II+1
      GO TO 5020
5080  WRITE(6,5085)
5085  FORMAT('0EOF ENCOUNTERED ON I/P'////)
      GO TO 2100
5090  WRITE(6,5095)
5095  FORMAT('0ERROR IN READING I/P'////)
      GO TO 5020
5100  IF(BETA.NE.4H YES)GO TO 2100
C....SET INTENSITY SWITCHES
      WRITE(6,5105)
5105  FORMAT('0SET INTENSITY SWITCHES TO 1 2 3 1 2 3 2')
      IP=1
      DO 5130 II=1,351,10
      DO 5125 IJ=1,10
      IAZ=II+IJ-2
      GATE(1)=IAZ/100
      GATE(2)=MOD(IAZ,100)/10
      GATE(3)=MOD(IAZ, 10)
      DO 5126 IK=4,19
5126  GATE(IK)=0
      DO 5110 I=20,159
5110  GATE(I)=(I*8)/20
      DO 5112 I=160,219
5112  GATE(I)=IP*8
      CALL TPWRIT(11,GATE,220,$5115.$5120)
5125  CONTINUE
      IP=IP+1
      IF(IP.EQ.8)IP=1
5130  CONTINUE
      GO TO 2100
5115  WRITE(6,5116)
5116  FORMAT('0END OF O/P TAPE'////)
      GO TO 2100
5120  WRITE(6,5121)
5121  FORMAT('0ERROR IN WRITING ON O/P TAPE'////)
      GO TO 2100
      END
      FUNCTION LEGEN(K)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(120),MEN,COF(10,4,10),GATE(220),
     *IGD,BCXTM,  IHSK(19)
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IHSK
      LEGEN=0
      IF(K .GT. 0 .AND. K .LE. MEN)LEGEN=MAP(K)
      RETURN
      END
      SUBROUTINE CONTUR(INTEN,IAREA.AREA,IECINT,IGL)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(100),MEN,COF(10,4,10),GATE(220),
     *IGD,BCXTM,IHSK(19)
      DIMENSION AREA(10)
      DIMENSION IECINT(10)
      INTEGER BCXTM
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR IARY(360,220) ,GATE,IHSK
      DO 10 I=1,10
```

```
      DO 10 K=1,4
      DO 10 J=1,10
10    COF(I,K,J)=0.
      AREAMX=5*IAREA
      AREA=0.
3     I=1
      IECNO=1
      IGL=1
      JEGATE=199
5     CALL TPREAD(10,GATE,220,LENR,$500,$501)
      CALL TPWRIT(11,GATE,220,$502,$504)
      DO 200 K=1,19
200   IHSK(K)=GATE(K)
      CALL DECODE(IHSK,IAZ,ITLT,ISTC,JUL,ITIME,IDLY,IGL,ITC)
      IF(IAZ.GT.0)GO TO 203
      BDXTM=ITIME/100
      JTIM=BDXTM
      WRITE(6,204)
204   FORMAT('0DAY/ TIME/ TILT')
      WRITE(6,205)JUL,JTIM,ITLT
205   FORMAT(I4,2I6)
203   IF(I.EQ.1.AND.IAZ.NE.0)GO TO 5
      IF(IAZ.NE.I-1)GO TO 16
      DO 202 J=1,IGD
202   IARY(I,J)=0
      IST=IGD+20
      DO 201 J=IST,218
      IF(GATE(J).LT.INTEN)GATE(J)=0
201   IARY(I,J-19)=GATE(J)
      IARY(I,200)=0
      IF(IAZ.EQ.359)GO TO 15
      I=I+1
      GO TO 5
16    WRITE(6,17)
17    FORMAT('0*** - INVALID DATA.  AZIMUTH ERROR - ***')
      RETURN
15    IF(I.NE.360)GO TO 16
      J=JEGATE
      ISAV=360
C...ZERO OUT IECAZ AND IECRNG
      DO 905 IK=1,600
      IECRNG(1,IK)=0
      IECRNG(2,IK)=0
      IECAZ(1,IK)=0
905   IECAZ(2,IK)=0
      I=1
23    K=0
      AREA(IECNO)=0.
      MINTEN=56
      IP=3
C...LOCATE NORTHEAST CORNER OF ECHO
25    J=J-1
      JSAV=J
      IF(J.GT.IGD)GO TO 26
      I=I+1
      J=JEGATE
      IF(I.EQ.ISAV)RETURN
      GO TO 25
26    J1=J
      I1=I
      JMIN=J
      JMAX=J
      IMIN=I
      IMAX=I
      CALL BNDRY(IARY,I,J,I1,J1,$120)
      GO TO 25
C...SCAN FOR NEXT POINT
29    GO TO (155,35,45,55,65,75,85,95),IP
155   I1=I
      J1=J+1
      GO TO 101
35    I1=I-1
      IF(I1.EQ.0)I1=360
      J1=J+1
      GO TO 101
45    J1=J
      I1=I-1
      IF(I1.EQ.0)I1=360
      GO TO 101
```

```
55    J1=J-1
      I1=I-1
      IF(I1.EQ.0)I1=360
      GO TO 101
65    I1=I
      J1=J-1
      GO TO 101
75    I1=I+1
      IF(I1.EQ.361)I1=1
      J1=J-1
      GO TO 101
85    J1=J
      I1=I+1
      IF(I1.EQ.361)I1=1
      GO TO 101
95    J1=J+1
      I1=I+1
      IF(I1.EQ.361)I1=1
101   CALL BNDRY(IARY,I,J,I1,J1,$120)
      IP=IP+1
      ICOUNT=ICOUNT+1
      IF(IP.GT.8)IP=1
      IF(ICOUNT.GT.8)GO TO 125
      GO TO 29
120   K=K+1
      IF(K.EQ.900)STOP CONTUR
      J=J1
      I=I1
      IF(I-IMIN.GT.180)GO TO 122
      IF(I.LT.IMIN)IMIN=I
      IF(I.GT.IMAX)IMAX=I
      GO TO 123
122   IB=I-360
      IF(IB.LT.IMIN)IMIN=IB
123   IF(J.GT.JMAX)JMAX=J
      IF(J.LT.JMIN)JMIN=J
      IECAZ(2,K)=I
      IECRNG(2,K)=J
      IECAZ(1,K)=I-1
      IECRNG(1,K)=J
      IF(IARY(I,J).LT.MINTEN)MINTEN=IARY(I,J)
      IARY(I,J)=IARY(I,J)+100
      ICOUNT=1
      IF(IP-3)71,71,72
71    IP=IP+5
      GO TO 29
72    IP=IP-3
      GO TO 29
125   CONTINUE
      DO 160 L=1,K
      IA=IABS(IECAZ(2,K)-IECAZ(2,L))
      IF(IA.LE.1.OR.IA.GE.359)GO TO 165
      GO TO 159
165   IF(IABS(IECRNG(2,K)-IECRNG(2,L)).LE.1)GO TO 170
159   IARY(IECAZ(2,L),IECRNG(2,L))=IARY(IECAZ(2,L),IECRNG(2,L))-100
160   CONTINUE
      WRITE(6,161)IMIN,IMAX,JMIN,JMAX
161   FORMAT('0ECHO BETWEEN',2I4,' AZ. AND',2I4,' RANGE NOT CONTOURABLE'
     *)
      RETURN
170   K=K+1
      IECAZ(1,K)=IECAZ(1,L)
      IECRNG(1,K)=IECRNG(1,L)
      IF(JMIN.EQ.1)JMIN=2
      MAXINT=INT
      IHOLD=IMIN
      MINTEN=MINTEN+4
180   I=IMIN
      IF(IMIN.LT.1)I=360+IMIN
      DO 220 J=JMIN,JMAX
      IF(IARY(I,J-1).GT.100.AND.IARY(I,J).GT.0.AND.IARY(I,J).LT.64)
     *IARY(I,J)=IARY(I,J)+100
      IM=I-1
      IF(IM.EQ.0)IM=360
      IF(IARY(IM,J).GT.100.AND.IARY(I,J).GT.0.AND.IARY(I,J).LT.100)
     *IARY(I,J)=IARY(I,J)+100
      IF(IARY(I,J).LT.100)GO TO 220
      IF((IARY(I,J)-100).GT.MAXINT)MAXINT=IARY(I,J)-100
220   CONTINUE
```

```
      DO 221 J=JMIN,JMAX
      IF(IARY(I,J).GT.1?.)AREA(IECNO)=AREA(IECNO)+FLOAT(IGL*IGL*(2*J-1))
     **3.725646E-5
221   CONTINUE
      IMIN=IMIN+1
      IF(IMIN.LE.IMAX)GO TO 188
      IF(AREA(IECNO).LT.AREAMX)GO TO 191
      IMIN=IHCLD
222   I=IMIN
      IF(IMIN.LT.1)I=360+IMIN
      DO 223 J=JMIN,JMAX
      IF(IARY(I,J).LT.1?.)GO TO 223
      IARY(I,J)=IARY(I,J)-100
      IF(IARY(I,J).LE.MINTEN)IARY(I,J)=0
223   CONTINUE
      IMIN=IMIN+1
      IF(IMIN.LE.IMAX)GO TO 222
      I=IHCLD
      IF(IHCLD.LT.1)I=1
      J=JSAV
      GO TO 195
191   IMIN=IHCLD
192   I=IMIN
      IF(I.LT.1)I=360+IMIN
      DO 190 J=JMIN,JMAX
      IF(IARY(I,J).GT.1?.)IARY(I,J)=0
190   CONTINUE
      IMIN=IMIN+1
      IF(IMIN.LE.IMAX)GO TO 192
      I=IHCLD
      IF(IHCLD.LT.1)I=1
      J=JSAV
      IF(AREA(IECNO).LT.FLOAT(IAREA))GO TO 23
      IF(K-L.LT.4)GO TO2?
195   CALL CSTLNC(L,K)
      IECINT(IECNO)=MINTEN/8
      IECNO=IECNO+1
      IF(IECNO.LT.11)GO TO 23
      IF(I.LT.360)WRITE(6,196)
196   FORMAT('TEN ECHOES FOUND BEFORE PPI COMPLETED, RESET ECHO LIMITS')
      RETURN
500   WRITE(6,506)
506   FORMAT('0EOF ENCOUNTERED ON 10'////)
      STOP CONTUR
501   WRITE(6,507)
507   FORMAT('0ERROR IN READING ON 10'////)
      RETURN
502   WRITE(6,503)
503   FORMAT(1H0,23HEND OF TAPE ENCOUNTERED////)
      STOP CONTUR
504   WRITE(6,505)
505   FORMAT(1H0,23HERROR IN WRITING ENCOUNTERED////)
      RETURN
      END
      SUBROUTINE SETLIN(LINE)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(100),MEN,COF(12,4,10),GATE(220),
     *IGD,BCXTN,IHSK(19)
      CHAR IECRNG
      INTEGER*2 IECAZ
      CHAR GATE,IHSK
      A=XB(LINE)
      B=YB(LINE)
      C=XE(LINE)
      D=YE(LINE)
      SL(LINE)=(D-B)/(C-A)
      CALL ARCTAN(A,B,E)
      CALL ARCTAN(C,D,F)
      IF(A.EQ.0..AND.B.EQ.0.)E=F
      IF(C.EQ.0..AND.D.EQ.0.)F=E
      IF(E.EQ.F)GO TO 5
      IF(E-F.GE.179.5)GO TO 3
      IF(F-E.GE.179.5)GO TO 4
      GO TO 5
3     XE(LINE)=0.
      YE(LINE)=B-SL(LINE)*A
      PHIB(LINE)=E
      PHIE(LINE)=360.
```

```
      IF(YE(LINE).LT.1.)PHIE(LINE)=E
      LINE=LINE+1
      XB(LINE)=Ø
      YB(LINE)=YE(LINE-1)
      SL(LINE)=SL(LINE-1)
      PHIB(LINE)=Ø.
      PHIE(LINE)=F
      IF(YB(LINE).LT.1.)PHIB(LINE)=F
      XE(LINE)=C
      YE(LINE)=D
      RETURN
4     XB(LINE)=Ø.
      YB(LINE)=B-SL(LINE)*A
      XE(LINE)=A
      YE(LINE)=B
      PHIB(LINE)=Ø.
      PHIE(LINE)=E
      IF(YE(LINE).LT.1.)PHIB(LINE)=E
      LINE=LINE+1
      XB(LINE)=C
      YB(LINE)=D
      XE(LINE)=Ø.
      YE(LINE)=YB(LINE-1)
      PHIB(LINE)=F
      PHIE(LINE)=36Ø.
      IF(YE(LINE).LT.1.)PHIE(LINE)=F
      SL(LINE)=SL(LINE-1)
      RETURN
5     IF(E.LT.F)GO TO 2
      PHIB(LINE)=F
      PHIE(LINE)=E
      RETURN
2     PHIB(LINE)=E
      PHIE(LINE)=F
      RETURN
      END
      SUBROUTINE ARCTAN(U,V,THETA)
      RTD=57.29577951
      IF(U.EQ.Ø..AND.V.GE.Ø.)THETA=Ø.
      IF(U.EQ.Ø..AND.V.LT.Ø.)THETA=18Ø.
      IF(U.GT.Ø.)THETA=9Ø.-ATAN(V/U)*RTD
      IF(U.LT.Ø.)THETA=27Ø.-ATAN(V/U)*RTD
      RETURN
      END
      SUBROUTINE ISORT(V,KY,N)
      REAL V(2)
      INTEGER KY(2)
C        INITAILIZE KEY AND POINTERS
      DO 2Ø I=1,N
   2Ø KY(I)=I
      KØ=1
      NØ=N-1
      NK1=NØ
C        TEST FOR END OF SORT
   25 IF(NK1 .LE. Ø)RETURN
C        NOT FINISHED.  START NEXT PASS.
      K1=NK1
      NK1=Ø
      DO 3Ø J=KØ,K1
      M1=KY(J)
      M2=KY(J+1)
      IF(V(M1) .LE. V(M2))GO TO 3Ø
      KY(J)=M2
      KY(J+1)=M1
      IF(NK1 .EQ. Ø)KØ=J-1
      NK1=J+1
   3Ø CONTINUE
      KØ=MAXØ(1,KØ)
      NK1=MINØ(NØ,NK1)
      GO TO 25
      END
      SUBROUTINE ECHO(IECH)
      COMMON XB(9ØØ),XE(2ØØ),YB(9ØØ),YE(2ØØ),SL(2ØØ),PHIB(2ØØ),PHIE(2ØØ)
     *,ISVGT(4Ø),GTMIN(4Ø),GTMAX(4Ø),SLENG(1Ø),NFAM(1Ø),IECAZ(1Ø,9ØØ),
     *IECRNG(1Ø,9ØØ),IECNO,IGTLENG,MAP(1ØØ),MEN,COF(1Ø,4,1Ø),GATE(22Ø),
     *IGC,BCXTM,IFSK(19)
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IFSK
```

```
      PI=3.1415926
      IE=SLENG(IECH)
      IHAM=NHAM(IECH)
      DO 4  I=1,IE
      Y=COF(1,3,IECH)
      X=COF(1,1,IECH)
      DO 405  N=2,IHAM
      U=2.*(N-1)*PI*I/FLOAT(IE)
      COSU=COS(U)
      SINU=SIN(U)
      X=X+COF(N,1,IECH)*COSU+COF(N,2,IECH)*SINU
      Y=Y+COF(N,3,IECH)*COSU+COF(N,4,IECH)*SINU
405   CONTINUE
      IECRNG(IECH,I)=SQRT(X*X+Y*Y)/FLOAT(IGTLENG)+20.
      CALL ARCTAN(X,Y,AZ)
      IECAZ(IECH,I)=AZ
4     CONTINUE
      RETURN
      END
      SUBROUTINE LNSORT(LNMAX,IPOINT,MXNOLN)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(100),MEN,COF(10,4,10),GATE(200),
     *IGD,BCXTM,IHSK(19)
      DIMENSION IPCINT(200),PHIHOLD(200)
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IHSK
      DO 197 J=1,200
      PHIHOLD(J)=0.
197   IPCINT(J)=0
      DO 203 J=1,MXNOLN
      ICOUNT=0
      DO 202 I=1,MXNOLN
      IF(PHIHOLD(I).EQ.999.)GO TO 202
      ICOUNT=ICOUNT+1
      IF(ICOUNT.EQ.1)GO TO 198
      IF(PHIB(I)-PHIMIN)198,199,202
198   IPCINT(J)=I
      PHIMIN=PHIB(I)
      PHEND=PHIE(I)
      GO TO 202
199   IF(PHEND-PHIE(I))202,202,198
202   CONTINUE
      LINE=IPCINT(J)
      PHIHOLD(LINE)=999.
203   CONTINUE
      IF(MXNOLN.GE.200)STOP LNSORT2
      DO 902  I=1,360
      IAZ=I-1
      LNCNT=0
      DO 901  J=1,MXNOLN
      K=IPCINT(J)
      IF(PHIB(K).LE.IAZ.AND.PHIE(K).GE.IAZ)LNCNT=LNCNT+1
901   CONTINUE
      IF(I.EQ.1)GO TO 903
      IF(LNCNT.LE.LNMAX)GO TO 902
903   LNMAX=LNCNT
      IF(LNMAX.GT.40)STOP LNSORT4
902   CONTINUE
      IF((LNMAX+MXNOLN).GT.200)STOP LNSORT3
      DO 206  L=1,LNMAX
      IPCINT(L+MXNOLN)=L+MXNOLN
206   XB(L+MXNOLN)=999.
      MXNOLN=MXNOLN+LNCNT
      RETURN
      END
      SUBROUTINE GETLIN(ILNE,L,IPOINT)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(100),MEN,COF(10,4,10),GATE(200),
     *IGD,BCXTM,IHSK(19)
      DIMENSION IPCINT(200)
      INTEGER BCXTM
      INTEGER GTMIN,GTMAX
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IHSK
      ISVGT(L)=0
```

```
57    ILNE=ILNE+1
      IF(ILNE.GT.200)STOP GETLIN
      J=IPOINT(ILNE)
      IF(XB(J).EQ.999.)RETURN
      A=XB(J)
      B=YB(J)
      C=XE(J)
      D=YE(J)
      R1=SQRT(A*A+B*B)
      R2=SQRT(C*C+D*D)
      R3=20 .*FLOAT(IGTLENG)
      IF(R1.GT.R3.AND.R2.GT.R3)GO TO 57
      IF(R1-R2)76,76,74
76    GTMIN(L)=R1/FLOAT(IGTLENG)+20.
      GTMAX(L)=R2/FLOAT(IGTLENG)+20.
      GO TO 75
74    GTMIN(L)=R2/FLOAT(IGTLENG)+20.
      GTMAX(L)=R1/FLOAT(IGTLENG)+20.
75    IF(GTMAX(L).GT.220)GTMAX(L)=220
      RETURN
      END
      SUBROUTINE TIMOFF(ID1,IT1,ID2-IT2,IOFF,ITFF)
      IOFF=0
      ITFF=0
      IDAY1=ID1
      IDAY2=ID2
      IHR1=IT1/10000
      IMIN1=(IT1-IHR1*10000)/100
      ISEC1=IT1-(IHR1*10000+IMIN1*100)
      IHR2=IT2/10000
      IMIN2=(IT2-IHR2*10000)/100
      ISEC2=IT2-(IHR2*10000+IMIN2*100)
      IF(ID1-ID2)1,4,5
4     IF(IT1.EQ.IT2)RETURN
      IF(IT1.GT.IT2)GO TO 5
1     IF(ISEC2.GE.ISEC1)GO TO 2
      ISEC2=ISEC2+60
      IMIN2=IMIN2-1
2     ISCDF=ISEC2-ISEC1
      IF(IMIN2.GE.IMIN1)GO TO 3
      IMIN2=IMIN2+60
      IHR2=IHR2-1
3     IMNDF=IMIN2-IMIN1
      IF(IHR2.GE.IHR1)GO TO 9
      IHR2=IHR2+24
      IDAY2=IDAY2-1
9     IHRDF=IHR2-IHR1
      IOFF=IDAY2-IDAY1
      ITFF=-(ISCDF+100*(IMNDF+100*IHRDF))
      RETURN
5     IF(ISEC1.GE.ISEC2)GO TO 6
      ISEC1=ISEC1+60
      IMIN1=IMIN1-1
6     ISCDF=ISEC1-ISEC2
      IF(IMIN1.GE.IMIN2)GO TO 7
      IMIN1=IMIN1+60
      IHR1=IHR1-1
7     IMNDF=IMIN1-IMIN2
      IF(IHR1.GE.IHR2)GO TO 8
      IHR1=IHR1+24
      IDAY1=IDAY1-1
8     IHRDF=IHR1-IHR2
      IOFF=IDAY1-IDAY2
      ITFF=ISCDF+100*(IMNDF+100*IHRDF)
      RETURN
      END
      SUBROUTINE BNDRY(IARY,I,J,I1,J1,*)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVCT(40),GTMIN(40),GTMAX(40),SLENG(10),NHAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(100),MEN,COF(10,4,10),GATE(220),
     *IGD,BDXTM,IHSK(19)
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR IARY(360,220) ,GATE,IHSK
      IF(IARY(I1,J1).GT.100)RETURN
      IF(IARY(I1,J1).LE.0)RETURN
      IF(IARY(I,J1).EQ.0.AND.IARY(I1,J).EQ.0)RETURN
      IF(J1.GT.200)STOP BNDRY
      ICNT=0
```

```
      I2=I1-1
      I3=I1+1
      IF(I2.EQ.Ø)I2=36Ø
      IF(I3.EQ.361)I3=1
      IB=IARY(I1,J1+1)
      ID=IARY(I2,J1)
      IG=IARY(I1,J1-1)
      II=IARY(I3,J1)
      IF(IB.EQ.Ø)ICNT=ICNT+1
      IF(ID.EQ.Ø)ICNT=ICNT+1
      IF(IG.EQ.Ø)ICNT=ICNT+1
      IF(II.EQ.Ø)ICNT=ICNT+1
      IF(ICNT.EQ.Ø)RETURN
      IC=IARY(I2,J1+1)
      IE=IARY(I2,J1-1)
      IH=IARY(I3,J1-1)
      IJ=IARY(I3,J1+1)
      IF(IB.NE.Ø.AND.IC.NE.Ø)GO TO 2
      IF(IC.NE.Ø.AND.ID.NE.Ø)GO TO 2
      IF(ID.NE.Ø.AND.IE.NE.Ø)GO TO 2
      IF(IE.NE.Ø.AND.IG.NE.Ø)GO TO 2
      IF(IG.NE.Ø.AND.IH.NE.Ø)GO TO 2
      IF(IH.NE.Ø.AND.II.NE.Ø)GO TO 2
      IF(II.NE.Ø.AND.IJ.NE.Ø)GO TO 2
      IF(IJ.NE.Ø.AND.IB.NE.Ø)GO TO 2
      IARY(I1,J1)=Ø
      RETURN
2     IF(II.EQ.Ø.AND.ID.EQ.Ø.AND.ICNT.EQ.2)GO TO 1
      IF(IB.EQ.Ø.AND.IG.EQ.Ø.AND.ICNT.EQ.2)GO TO 1
      IF(ICNT.LT.4)RETURN
1     IARY(I1,J1)=Ø
      RETURN
      END
      SUBROUTINE CSTLNE(L,K)
      COMMON XB(9ØØ),XE(2ØØ),YB(9ØØ),YE(2ØØ),SL(2ØØ),PHIB(2ØØ),PHIE(2ØØ)
     *,ISVGT(4Ø),GTMIN(4Ø),GTMAX(4Ø),SLENG(1Ø),NHAM(1Ø),IECAZ(1Ø,9ØØ),
     *IECRNG(1Ø,9ØØ),IECNO,IGTLENG,MAP(1ØØ),MEN,COF(1Ø,4,1Ø),GATE(22Ø),
     *IGD,EDXTM,IHSK(19)
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IHSK
      DTR=.Ø174533
      DF=1.E-4
      PI=3.1415926
      IECH=IECNO
      MCOUNT=K-L+1
      IHAM=9
      IF(MCOUNT.LT.18)IHAM=MCOUNT/2+1
      NHAM(IECH)=IHAM
      DO 1 J=1,1Ø
      DO 1 I=1,4
1     COF(J,I,IECH)=Ø.
      A=IECAZ(1,L)
      R=IECRNG(1,L)
      XS1=R*SIN(A*DTR)
      YS1=R*COS(A*DTR)
      XLENG=Ø.
      L1=L+1
      DO 6 I=L1,K
      A=IECAZ(1,I)
      R=IECRNG(1,I)
      XB(I)=R*SIN(A*DTR)
      YB(I)=R*COS(A*DTR)
      XS=XB(I)
      YS=YB(I)
      XLENG=XLENG+SQRT((XS-XS1)**2+(YS-YS1)**2)
      XS1=XS
      YS1=YS
6     CONTINUE
      SLENG(IECH)=XLENG
      DO 2ØØ NH=2,IHAM
      N=NH-1
      S1=Ø.
      DO 1ØØ I=L1,K
      XS=XB(I)
      YS=YB(I)
      S2=S1+SQRT((XS-XS1)**2+(YS-YS1)**2)
      IF(ABS(S1-S2).LE.DF)GO TO 1ØØ
      PX=(XS-XS1)/(S2-S1)
```

```
      PY=(YS-YS1)/(S2-S1)
      QX=XS-PX*S2
      QY=YS-PY*S2
      CN=2*N*PI/XLENG
      U1=CN*S1
      U2=CN*S2
      SIN1=SIN(U1)
      SIN2=SIN(U2)
      COS1=COS(U1)
      COS2=COS(U2)
C     DO COEFF OF COSINE FOR X COORDS
      T2=QX/CN*SIN2+PX*(CN**(-2)*COS2+S2/CN*SIN2)
      T1=QX/CN*SIN1+PX*(CN**(-2)*COS1+S1/CN*SIN1)
      COF(NF,1,IECH)=COF(NF,1,IECH)+2./XLENG*(T2-T1)
C     DO COEFF OF SINE FOR X COORDS
      T2=-QX/CN*COS2+PX*(CN**(-2)*SIN2-S2/CN*COS2)
      T1=-QX/CN*COS1+PX*(CN**(-2)*SIN1-S1/CN*COS1)
      COF(NF,2,IECH)=COF(NF,2,IECH)+2./XLENG*(T2-T1)
C     DO COEFF OF COSINE FOR Y COORDS
      T2=QY/CN*SIN2+PY*(CN**(-2)*COS2+S2/CN*SIN2)
      T1=QY/CN*SIN1+PY*(CN**(-2)*COS1+S1/CN*SIN1)
      COF(NF,3,IECH)=COF(NF,3,IECH)+2./XLENG*(T2-T1)
C     DO COEFF OF SINE FOR Y COORDS
      T2=-QY/CN*COS2+PY*(CN**(-2)*SIN2-S2/CN*COS2)
      T1=-QY/CN*COS1+PY*(CN**(-2)*SIN1-S1/CN*COS1)
      COF(NF,4,IECH)=COF(NF,4,IECH)+2./XLENG*(T2-T1)
      S1=S2
      XS1=XS
      YS1=YS
100   CONTINUE
200   CONTINUE
C     CALCULATE ZERO HARMONIC COEFF
      COF(1,2,IECH)=0.
      COF(1,4,IECH)=0.
      S1=0.
      DO 300 I=L1,K
      XS=XB(I)
      YS=YB(I)
      S2=SQRT((XS-XS1)**2+(YS-YS1)**2)+S1
      IF(ABS(S1-S2).LE.DF)GO TO 300
      PX=(XS-XS1)/(S2-S1)
      PY=(YS-YS1)/(S2-S1)
      QX=XS-PX*S2
      QY=YS-PY*S2
      T2=.5*PX*S2**2+QX*S2
      T1=.5*PX*S1**2+QX*S1
      COF(1,1,IECH)=COF(1,1,IECH)+(T2-T1)/XLENG
      T2=.5*PY*S2**2+QY*S2
      T1=.5*PY*S1**2+QY*S1
      COF(1,3,IECH)=COF(1,3,IECH)+(T2-T1)/XLENG
      S1=S2
      XS1=XS
      YS1=YS
300   CONTINUE
      RETURN
      END
      SUBROUTINE ELLIPS(XM,TANW,XK,ELPS,IECH)
      COMMON XB(900),XE(200),YB(900),YE(200),SL(200),PHIB(200),PHIE(200)
     *,ISVGT(40),GTMIN(40),GTMAX(40),SLENG(10),NPAM(10),IECAZ(10,900),
     *IECRNG(10,900),IECNO,IGTLENG,MAP(120),MEN,COF(10,4,10),GATE(220),
     *IGC,BOXTM,IHSK(19)
      DIMENSION ELPS(3)
      INTEGER*2 IECAZ
      CHAR IECRNG
      CHAR GATE,IHSK
      A=COF(2,1,IECH)
      B=COF(2,2,IECH)
      C=COF(2,3,IECH)
      D=COF(2,4,IECH)
      IF(B.NE.0..OR.C.NE.0.)GO TO 1
      XK=SQRT(A*A+D*D)
      TANW=-1./XM
      ELPS=0.
      GO TO 2
1     A2=A*A
      B2=B*B
      C2=C*C
      D2=D*D
      AC=A*C
```

```
      AB=A*B
      AD=A*D/2.
      BC=B*C/2.
      BD=B*D
      CD=C*D
      DEN=A2*(BD*CD-(AD+BC)*D2)-AC*(B2*CD-AB*D2)+C2*(B2*(AD+BC)-AB*BD)
      XK=SQRT(A2+B2+C2+D2)
      FN1=XK*(BD*CD-(AD+BC)*D2)-AC*(XK*CD)+C2*(XK*(AD+BC))
      FN2=A2*(XK*CD)-XK*(B2*CD-AB*D2)+C2*(-AB*XK)
      FN3=A2*(-(AD+BC)*XK)-AC*(-AB*XK)+XK*(B2*(AD+BC)-AB*BD)
      ELPS(1)=FN1/DEN
      ELPS(2)=FN2/DEN
      ELPS(3)=FN3/DEN
      W=ATAN(ELPS(2)/(ELPS(1)-ELPS(3)))/2.
      TANW=TAN(W)
      SINW=SIN(W)
      COSW=COS(W)
      APRIM=ELPS(1)*COSW**2+ELPS(2)*SINW*COSW+ELPS(3)*SINW**2
      CPRIM=ELPS(1)*SINW**2-ELPS(2)*SINW*COSW+ELPS(3)*COSW**2
      IF(APRIM.GT.CPRIM)TANW=-1./TANW
      IF(ABS(ATAN(TANW)-ATAN(XM)).GT..174533 )GO TO 2
      XK=AMIN1(SQRT(A2+B2),SQRT(C2+D2))
      TANW=-1./XM
2     RETURN
      END
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