ILLINOIS STATE WATER SURVEY
METEOROLOGIC LABORATORY
at the
University of Illinois
Urbana, Illinois

TECHNICAL REPORT NO.1

WIND DATA FROM RADAR ECHOES

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ILLINOIS STATE WATER SURVEY

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ABSTRACT

The upper level wind structures associated with two types of radar echoes under differing synoptic situations were investigated.

Sixty-nine cases of precipitation echo movements, observed on the PPI scope of a 3-cm radar, were correlated with the winds aloft. These cases were selected without regard to synoptic conditions favorable for correlation purposes. The selection was based solely upon the availability of radar and upper wind data. The echoes were classified into two groups, one of elements of squall lines and another of isolated echoes. Plots were made of these echoes on a base map, and the speed and direction of their movements were correlated with the upper winds obtained from streamline charts.

The movements of the echoes were correlated with the mean wind for three layers: 2000-20,000 ft, 2000-26,000 ft, and 6000-30,000 ft; and with winds at three individual levels: 6000 ft, 10,000 ft, and 20,000 ft.

Results show that radar echoes can be used for obtaining the mean wind speed and direction for different layers and the wind speed and direction at specific levels. The standard error of estimate was computed for each layer and level investigated to ascertain at which of these layers and levels the wind velocity can be determined with the greatest accuracy.

Graphical presentations of the results are made. Nomograms for operational use are presented and applications of radar data are discussed.

INTRODUCTION

Purpose

This investigation was made to develop techniques for obtaining upper wind data from radar echo movements. During extended periods of low cloudiness and precipitation pilot balloon data are not obtainable. Wind data are needed at sea to insure efficient fleet operation and over remote land areas where upper air sounding stations are sparse or lacking. Furthermore, it is often impossible to launch balloons for upper wind data from ships underway because of strong apparent winds when the ship is heading into the wind.

Radar data can be used to obtain wind velocity vectors to aid in computing fuel consumption rates for aircraft, and for computing ballistics for long-range gunnery. The radar observations can be further utilized as forecasting aids in determining synoptic patterns within the immediate area and for ascertaining the movement of squall lines or zones.

Scope

The study was limited to an investigation of unstable summertime conditions, involving rain shower and thundershower situations. Radar echo movements, as portrayed on the PPI (Plan-Position Indicator) scope, were correlated with the upper air circulation, as indicated by streamline charts constructed from 6-hourly PIBAL and RAWIN observations made by Weather Bureau and Air Force stations over the Mid-West.

In determining the accuracy with which upper Wind Data can be obtained from radar echo movements, it was assumed that the forecaster would have only PPI scope data available, and would not have access to surface and upper air synoptic maps or other forecasting aids. Since cloud movements with summertime shower activity are normally subjected to the effects of variable wind flow within a relatively deep atmospheric layer, efforts were concentrated on relating radar echo movements to layer mean winds.

The results are indicative of the utility of radar with PPI presentation in determining the upper wind flow under adverse weather conditions. With the availability of RHI (Range-Height Indicator) radar and limited synoptic weather information, accuracy should be considerably improved.

EQUIPMENT

The chief source of radar data used in conjunction with this wind study has been a modified AN/APS-15A radar set, operating at a wavelength of 3 cm, a peak power output of about 25 kw, and a range of approximately 150 miles.

This radar set has been equipped with an automatic gain reduction device, which reduces the receiver sensitivity in a stepwise fashion (6). As the sensitivity is reduced, heavier rainfall rates are required to produce a detectable signal. The signal produced on the PPI (Plan-Position Indicator) scope by the precipitation area for each gain step is photographed by a 35-mm Navy "type A" scope camera. A series of 10 gain steps are available and pictures are taken at intervals of about 5.5 sec.

DATA

The radar data used were collected from June through September, 1951, and from mid-June through mid-November, 1952, at Champaign, Illinois. Two cases were also selected from data collected during the summer of 1950 at El Paso, Illinois. The remaining data for the above periods were unsatisfactory for analysis. The principal cause of data rejection was too short a sequence, since the operating procedure often called for a change in antenna tilt or a reduction in the range in order to collect specialized data for other projects. Sixty-nine cases of radar echoes were investigated.

The movements of both isolated echoes and elements of squall lines were correlated with the mean wind direction and speed for three layers: 2000-20,000 ft, 2000-26,000 ft, and 6000-30,000 ft; and with the wind direction and speed for three individual levels: 6000 ft, 10,000 ft, and 20,000 ft.

Figures 4 illustrates an element of a squall line which was chosen for analysis - This element had sufficient speed and definition so that its movement could be traced for a 30-minute period. Several of the streamline charts used for determining the upper winds associated with the movement of the elements of the squall line in Figure 4 are presented in Figure 5. This case is discussed under the section on "Elements of Squall Lines".

DISCUSSION OF RESULTS

The movements of both isolated echoes and elements of squall lines were correlated with the wind velocities for the previously mentioned layers and levels to:

(1) find the best layer or level for correlation with each of the two classifications of echoes

(2) study the relation between echo movement and the overall wind field obtained from streamline analysis

(3) compare with the findings of previous investigators (1, 2, 4).

Isolated Echoes

Figures 1, 2, and 3 show a typical case in which a high correlation was obtained between the movement of an isolated echo and the mean wind direction and speed for the layer 2000-20,000 ft. This echo movement also gave a high correlation with the speed and direction at the 10,000-ft level, probably because this level represented the approximate mean for the layer.

Movements as related to mean winds for layers. A comparison of the movements of isolated echoes with the mean winds for the three investigated layers shows about equal correlations for the combination of speed and direction for the layers 2000-20,000 ft and 2000-26,000 ft (Fig. 6). The isolated echoes move close to the direction of the mean wind for these layers as indicated by the proximity of the regression line (line of best fit) to the 1:1 line in Figure 6-Graphs A and B. These echoes move faster than the mean wind speed in the case of higher speed echoes and slower than the wind for slower moving echoes. This is illustrated in Figure 6-Graph D, in which the regression line crosses the 1:1 line at about 18 knots. In general, this relation holds true for the other layers and levels, as shown by the regression lines intersecting the 1:1 lines with slopes less than one.

In order to determine the limits of accuracy of the results for application in determining winds, standard errors of estimate were computed with respect to the regression lines after sfewness tests had shown the data to be normally distributed about the regression lines. Two standard errors of estimate, which should include about 95% of the cases for all such samples, were computed. These are tabulated in Table III and are discussed with it.

These standard errors of estimate were computed using all of the isolated echo data and include some widely scattered points from the regression lines. Some of these echoes probably should not have been correlated with any of the investigated layers due to their low tops. However, the usage of these cases indicates the error in estimation that can occur in using PPI (Plan Position Indicator) radar data when the echo bases and tops are not known.

Movements as related to winds at specific levels. Figure 7 shows the movement of isolated echoes as related to the winds at three specific levels. The winds at the 10,000-ft level, as shown in Fig. 7-Graphs B and E, give the highest correlation with the echo movements considering both speed and direction. The winds at 20,000 ft show high correlation with echo movements with respect to direction, but rather low correlation with respect to speed (Fig. 7-Graphs C,F). The wind direction at 6000 ft agrees very closely with the echo direction; however, the speed correlation is the lowest of the three levels investigated (Fig. 7-Graphs A, D).

Standard errors of estimate were computed, using all 34 cases without regard to the vertical extent of the echoes, in order to check the accuracy of the results as a means for finding the wind speed and direction at each of the three levels. Two standard errors for the three levels are listed in Table III. The use of RHI radar for determining the bases and tops of echoes would probably increase the accuracy by aiding the forecaster in selecting echoes that should correlate best with a particular level.

Table I summarizes the correlation coefficients for isolated echoes as related to layer mean winds and winds at specific levels. A correlation coefficient is a relative measure of the extent to which two variables are related. Zero correlation indicates no relation and 1.0 indicates a perfect relation.

TABLE I

CORRELATION COEFFICIENTS FOR 34 CASES OF ISOLATED ECHOES

a. Wind Layers	Direction	Speed
2000-20,000 ft.	.87	.72
2000-26,000 ft.	.90	.67
6000-30,000 ft.	.88	.60
b. Specific Levels		
6000 ft.	.84	.44
10,000 ft.	.75	.62
20,000 ft.	.82	.54

The correlation coefficients for layer means are higher than those for specific levels. This is not surprising since the clouds are embedded in a layer and are not likely to be steered by winds at a specific level.

Elements of Squall Lines

Figures 4 and 5 illustrate a typical case in which a fair correlation was obtained between the movement of an element of a squall line and the mean wind for the layer 2000-26,000 ft. This squall line appeared to have a slight s-shape curvature or wave pattern, with elements at the center moving faster than those at the north and south ends. An element from the middle group of echoes was chosen for speed and direction computations because this group contained enough elements to establish the line orientation. The resultant vector "C" represents the path of a more intense core as observed on the scope photographs. The scope photographs showed some poorly defined echoes, not reproduced in Figure 4, between the middle group and the southern-most group south of Springfield, thus indicating that all of these echoes belonged to the same squall line or zone.

The dissipating echo south of Springfield had the same general direction of motion as that shown by vector C (Figure 4) in the central group but its speed was somewhat less. A comparison of the winds at Springfield and Chanute Field in Figure 5 indicated that lighter winds probably did exist south of Springfield, thus verifying the slower echo speed. The winds aloft for Joliet were missing at 0300 C.S.T. so that comparisions could not be made with echo movement in that vicinity. This is typical of many cases in which the upper wind data are not sufficient to explain the micro-scale differences in motion. The echo movements in such cases may give more reliable mean winds at a given time and place for the layers in which the echoes are embedded, than those obtainable from streamline charts made from the present-day upper air sounding networks.

Movements as related to mean winds for layers. A comparision of the movement of elements of a squall line with the mean winds for the three layers investigated shows that the highest correlation, considering both speed and direction, occurs with the layer 2000-26,000 ft (Fig. 8). However, the layers 2000-20,000 ft and 6000-30,000 ft give nearly as high correlation coefficients. The elements, in most cases, move in a direction 5 to 10 degrees to the right of the mean wind direction for the layer 2000-26,000 ft. The computed regression lines indicate that elements of squall lines, with speeds greater than about 30 knots, move faster than the mean wind speed for the layers 2000-26,000 ft and 6000-30,000 ft; while those with speeds greater than 20 knots move faster than the mean wind speed for the layer 2000-20,000 ft.

Standard errors of estimate from the regression lines for direction and speed were computed for the three layers. Two standard errors of estimate for these layers are listed in Table III.

Movements as related to winds at specific levels. Figure 9 shows the movement of elements of squall lines as related to winds at three specific levels. The winds at the 10,000-ft level give the highest direction and speed correlations with echo movements (Figure 9-Graphs B, E).

Two standard errors of estimate for speed and direction for each of the three levels are listed in Table III.

Table II gives the correlation coefficients for elements of squall lines as related to layer mean winds and winds at specific levels.

TABLE II

CORRELATION COEFFICIENTS FOR 35 CASES OF
ELEMENTS OF SQUALL LINES

A. Wind Layers	Direction	Speed
2000-20,000 ft	.79	.72
2000-26,000 ft	.84	.73
6000-30,000 ft	.82	.72
B. Specific Levels		
6000 ft	.56	.44
10,000 ft	.80	.68
20,000 ft	.63	.64

The correlation coefficients for the regression lines relating the movements of elements of squall lines to the layer mean winds are all higher than those relating the movements to winds at specific levels. This agrees with the results for isolated echoes discussed earlier, and affords further evidence that the echoes are steered by the wind layer in which they are embedded rather than by the wind at a particular level.

COMPARISON WITH OTHER STUDIES

Brooks (1), using 46 storms, reports that large storms move most frequently with the 11,000-ft winds, while small storms move most frequently with the 5000-ft winds. In a recent paper by Ligda (4), it was stated that convective cells in the New England area move essentially with the velocity of the 700-mb geostrophic wind- Ligda used data for one 12-month period which probably included a considerable amount of stable air mass precipitation types. The Water Survey's study was made from two years of summertime showers and thundershowers.

Since 6000-ft, 10,000-ft and 20,000-ft streamline charts had been drawn, in determining layer means, winds at these levels were correlated with echo movements to compare with the above authors findings. The results of this investigation are in fair agreement with Ligda, if it is desired to use a specific level instead of a layer mean. If isolated air mass showers can be considered as "small" storms, then the Water Survey's results are not in agreement with the findings of Brooks (See Table I b). Some of the disagreements are probably due to the differences in vertical extent of the storms studied by each investigator, which would have a bearing on their "steering". '

The Thunderstorm Project (2) using wind observations from their own network in the vicinity of the echoes, found that clouds move slower than the mean wind for the layer from the gradient level to 20,000 ft. Also, this difference was found to increase with increasing mean wind speeds. The Thunderstorm Project used the 4000-ft level as the gradient level in Ohio where the terrain was undulating and partially wooded. The Water Survey used the 2000-ft level as the gradient level over the flat agricultural land of central Illinois. The Water Survey and the Thunderstorm Project findings are in agreement for slow moving echoes but the Water Survey found that the fast moving echoes moved faster than the mean wind for the layer 2000-20,000 ft.

It must be remembered that the Water Survey study was concerned with the large scale wind structure, as it is related to the movement of radar echoes. It is possible that local maxima of wind speed exist in the vicinity of fast moving echoes. The echoes would move at a. speed less than these maxima, due to entrainment on the upwind side and detrainment on the downwind side (5), but could still maintain a speed greater than that of the broad scale wind field. This is further indicated by the fact that some of the fastest moving echoes in the Water Survey study had speeds greater than any values obtainable from streamline charts up to 30,000 ft or more. Therefore, maxima of speed, that were not shown by the upper air sounding stations, must have existed. The Water Survey data included more cases of high wind speed and high echo speed than did the Thunderstorm Project data. Probably with higher wind and echo speeds there is more spread between the echo speed, the local area wind speed in the vicinity of the echo, and the large scale wind speed.

LIMITATIONS IN ANALYZING DATA

Several inherent errors are incorporated into any study of this type. Some of these are:

1. Errors sometimes occur in collection, transmission and processing of the initial data.
2. Winds taken near a trough line when a squall line is in the trough are always subject to errors in placing the trough line with respect to the squall line. Several degrees difference in wind direction will result if winds are taken ahead of the trough line when they should have been taken to the rear, and conversely.
3. Differences in time of echo plots and wind observations may be significant if a trough line passes the echo area during the elapsed time. In this study efforts were made to correct for the time differences when trough lines were involved. In some cases, average winds from

two sets of streamline charts, six hours apart, were used for correlation with echo movement when the time of the echo plot fell midway between wind observations.

A resultant accuracy of + 10 degrees and + 5 knots is considered within the limits of such errors.

DEVIATIONS IN MOVEMENT OF RELATED ECHOES

Some deviations in the speed and direction of movement of different elements of squall lines have been observed. Similar deviations between the movement of some air mass thunderstorms located close to each other have also been noted.

Several explanations for these deviations follow:

1. The stage of development of a thunderstorm may effect the direction and speed of movement. During the early stages of development when updrafts are the strongest, the cloud may move with a velocity more nearly representing the lower level windsj while in the dissipating stage when downdrafts predominate, the cloud may move with a velocity more nearly representing the upper level winds. The use of RHI radar information should aid the forecaster in determining the best layer for correlation with echo movement.
2. Thunderstorm cells in weak squall lines may fluctuate rapidly so that accurate tracking of cells is very difficult. This is caused by their short life span and weak development.
3. Within areas of light rain, such as that in advance of warm fronts, areas of more intense precipitation are often visible. Natural seeding by ice crystals falling from cirrus clouds (3) may cause these areas of more intense precipitation to move with a velocity related to the winds at a higher level and result in poor correlations with lower level winds. Also, less well-defined cores of this type are more subject to short-

period shifts in position, through development and decay, than the heavy well-developed cores of thunderstorms.

4. Local variations of wind velocities in areas of strong convergence or divergence may produce deviations not detectable in the streamline patterns as constructed from the present-day upper air sounding network.

RULES FOR INCREASED ACCURACY OF WIND DETERMINATIONS

1. Use RHI data to determine the base and top of the echo where possible, and use these observations as an index in choosing which layer mean wind speed and direction can be most accurately predicted from the echo movement .
2. If RHI data is not available, plot the heaviest cores of echoes on the PPI scope. These are more likely to have sufficient vertical extent to reflect the upper level wind conditions. The cores can be determined more readily by reducing the receiver gain so that the lighter portions of the echoes disappear.
3. Areas of more intense precipitation within areas of light rain should be avoided, for reasons given previously under "Explanation of Deviations" (par. 3)
4. If the thunderstorm bases are likely to be high, e. g. in the case of warm air over-running over a cold dome, a higher-based layer, such as that from 6000-30,000 ft, should correlate best (Fig. 8-Graphs C, F) .
5. Use echoes within about 50 miles range of the radar station where possible so that more details of the development can be observed and cores of greatest intensity can more readily be distinguished. Echoes at greater ranges can be used with fair results.
6. Use echoes during the mature stage of development, or for a period incorporating the last stages of development and early stages of decay, in

order to obtain an average condition. The stage of development can be fairly well determined by observing the changes in areal extent on the PPI scope or by observing changes in vertical extent on the RHI.

APPLICATIONS

Nomograms for Winds

Figures 10 and 11 show nomograms for obtaining winds at three specific levels and mean winds for three layers from the movements of isolated echoes and elements of squall lines. These nomograms were constructed from the regression lines in Figures 6, 7, 8, and 9. The 95% confidence limits were taken from Table III.

In most cases the 10,000 ft winds are more nearly representative of the mean for the layer in which the echoes are embedded. For this reason the 10,000 ft winds can be determined with greater reliability than those at 6000 ft or 20,000 ft.

Determining Winds Over an Area

The wind field over an area of several thousand square miles can be estimated by making several plots along a squall line, such as that shown in Fig. 4, or by plotting several isolated echoes over the area.

Determining Synoptic Patterns

Streamlines and isotachs can be sketched, by tracking several widely spaced echoes, and from these inferences can be drawn as to the positions of lows and highs and the existing pressure gradients. This will work best for layer mean conditions; however, charts for the 10,000 ft level can also be constructed with considerable accuracy.

Movement of Frontal and Other Types of Squall Lines

The "normal vector", as shown in Fig. 4, can be used to forecast the future position of the lines or zones, while the "vector resultant" indicates the future position of individual elements of the line or zone.

CONCLUSIONS

The results indicate that both isolated echoes and elements of squall lines can be used with greater reliability for determining the mean wind speed and direction for a layer than for determining the wind at a specific level.

Both isolated echoes and elements of squall lines give more reliable wind data for the 10,000-ft level than for the 6000-ft or 20,000-ft level.

RHI radar information and synoptic conditions should be considered in selecting the layer that should correlate best with the movement of a particular echo.

It is likely that the echo movement gives more accurate wind data at a point than is obtainable from streamline charts using the present network of upper air soundings. The techniques presented in this report provide means for determining the broadscale wind structure from the localized echo observations.

DEFINITIONS

1. Isolated Echo movement is used to define the motion of an isolated echo not associated with a squall line (Fig. 1). This is the movement actually observed on the radar scope.
2. A squall line is arbitrarily defined as any line of thunderstorms.
3. The term element is applied to any individual echo in a squall line which is identifiable from one radar observation to the next (Fig. 4).
4. Line movement (Fig. 4).
    - A. Parallel vector-the vector component of movement of elements directed parallel to the axis of orientation of the squall line.
    - B. Normal vector-the vector component of movement of elements directed perpendicular to the squall line. This component of motion can be used to predict the future position of the squall line.

C. Vector Resultant-the resultant of the parallel and normal components as defined above. This corresponds to cell movement in the case of an isolated echo and is the actual movement of the squall line elements as observed on a radar scope. (This vector is used in the correlation of wind with echo movement).

ACKNOWLEDGEMENTS

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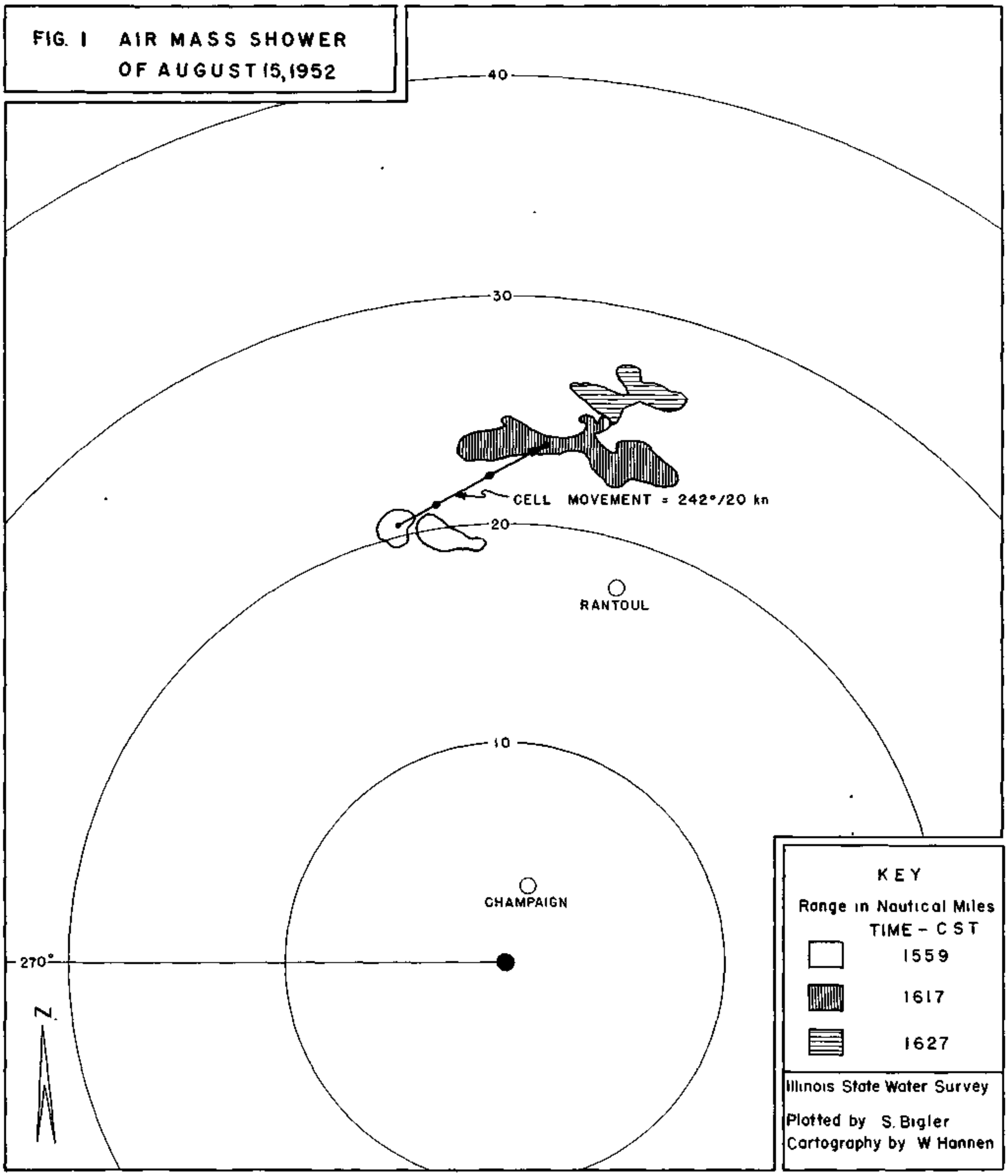
FIG. 1 AIR MASS SHOWER OF AUGUST 15, 1952



Illinois State Water Survey

Plotted by S. Bigler
Cartography by W Hannen

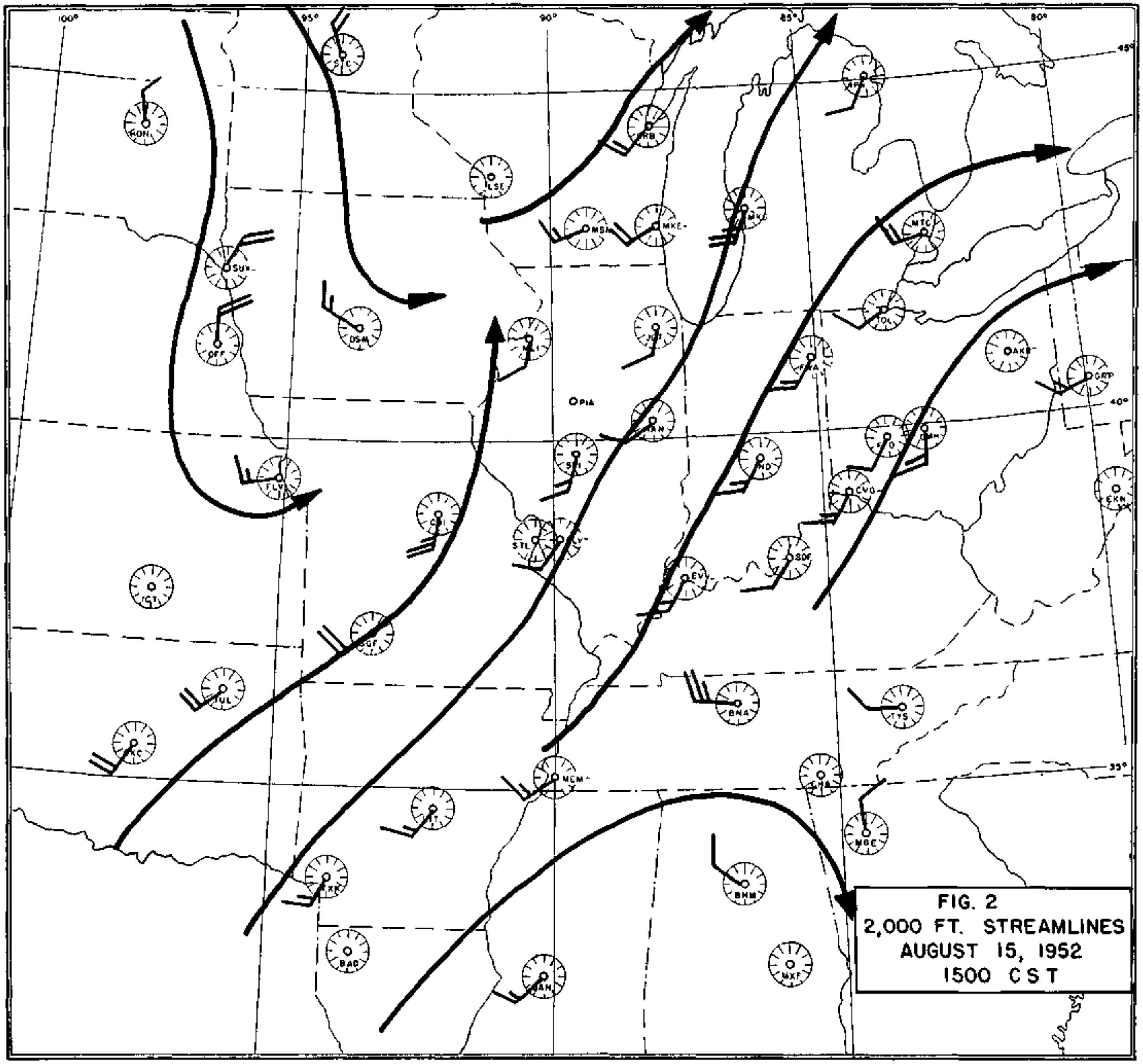
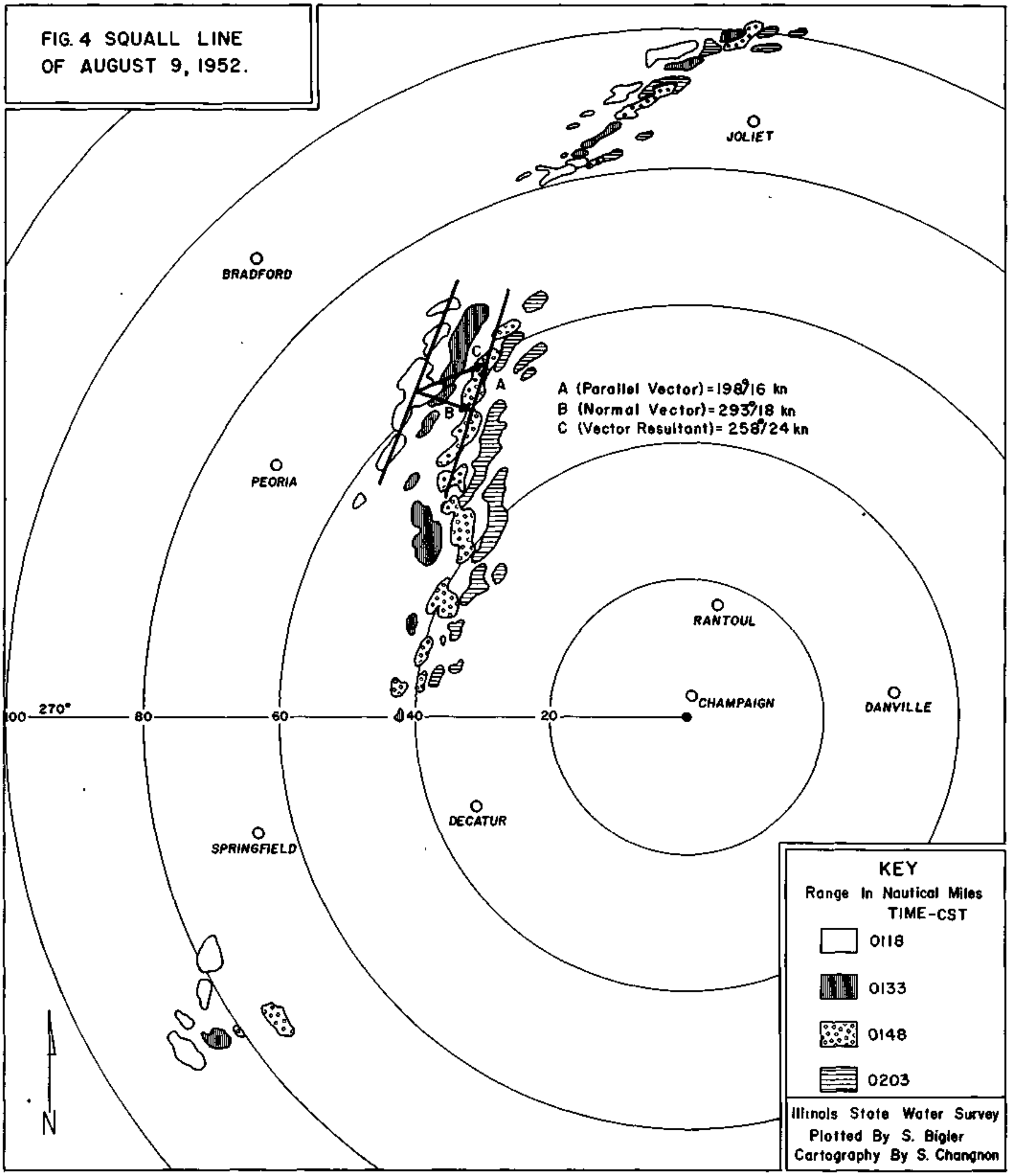


FIG. 2
2,000 FT. STREAMLINES
AUGUST 15, 1952
1500 CST

FIG. 4 SQUALL LINE OF AUGUST 9, 1952.



Illinois State Water Survey
Plotted By S. Bigler
Cartography By S. Changnon

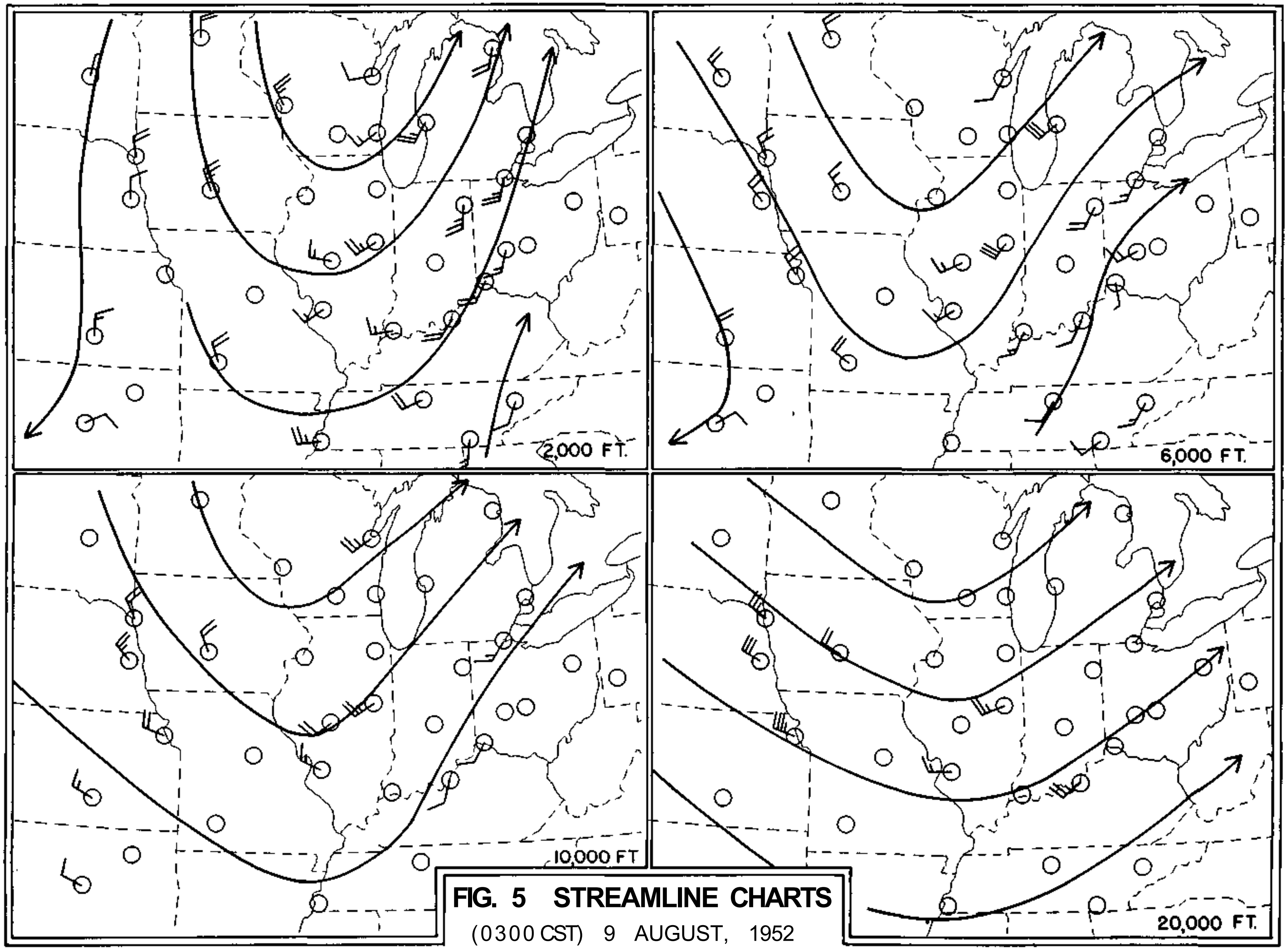


FIG. 5 STREAMLINE CHARTS

(0300 CST) 9 AUGUST, 1952

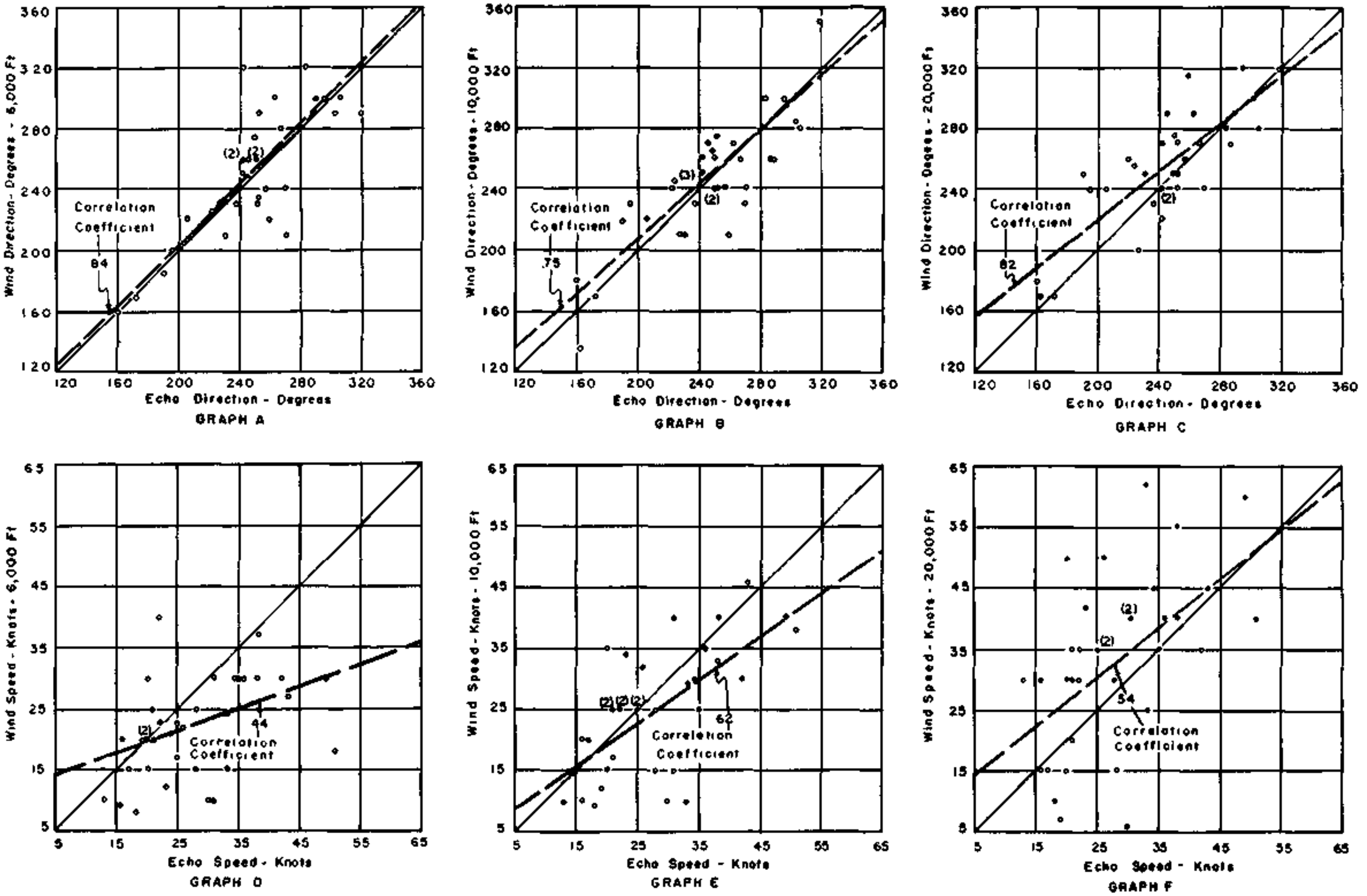


FIG. 7 RADAR ECHOES VS. WIND FOR THREE LEVELS
ISOLATED ECHOES

—— 1.1 LINE ---- REGRESSION LINE

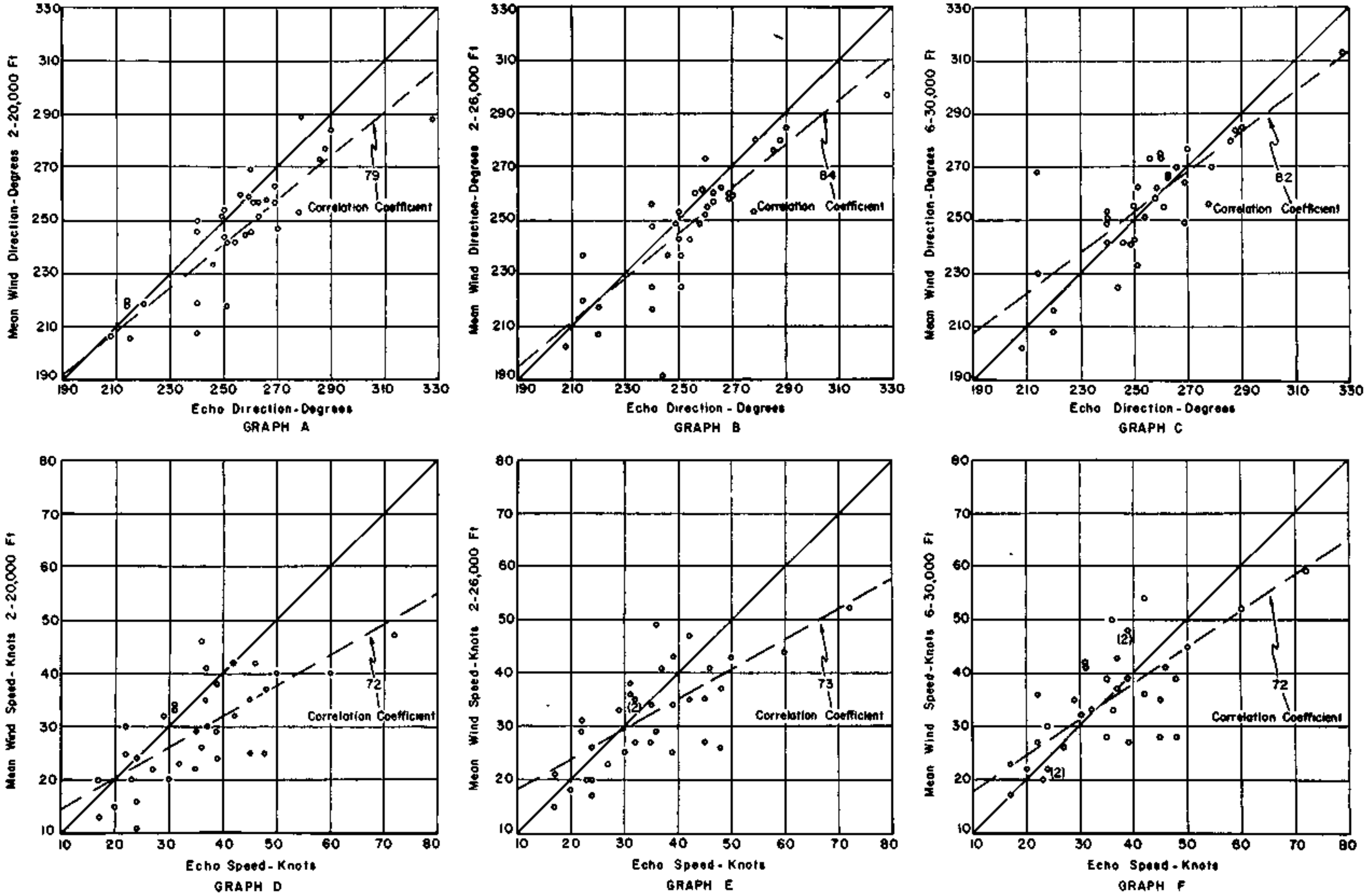


FIG. 8 RADAR ECHO VS MEAN WIND FOR THREE LAYERS
ELEMENTS OF A SQUALL LINE

—— 1:1 LINE ---REGRESSION LINE

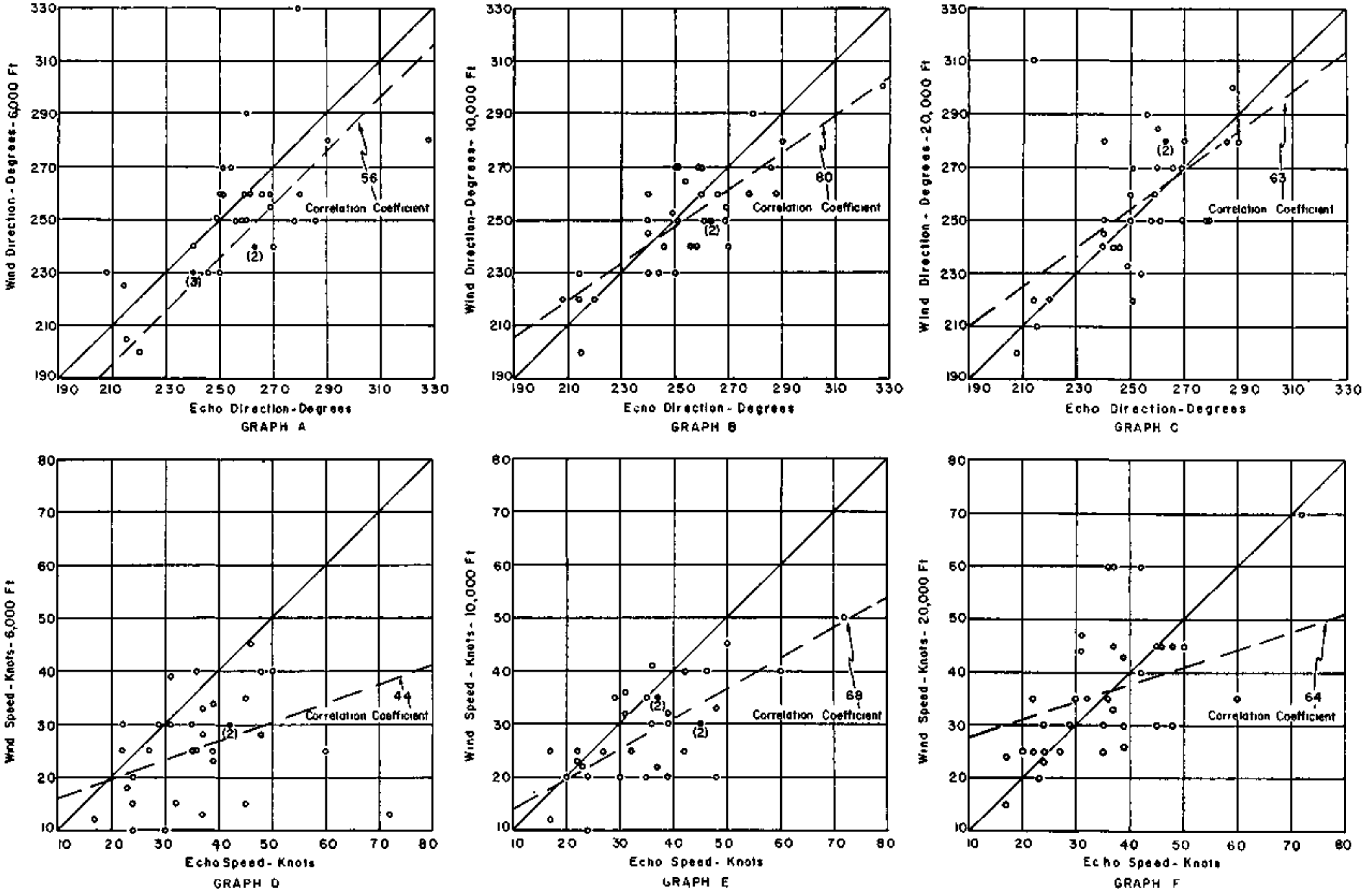
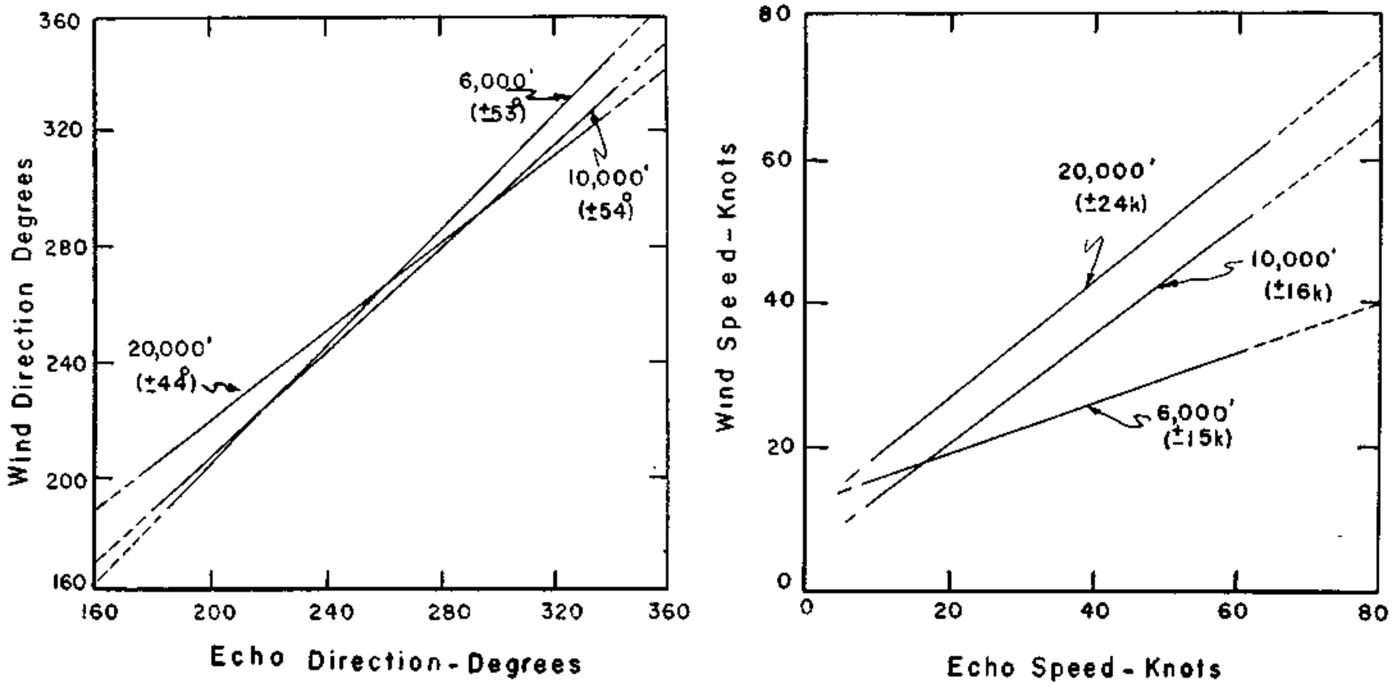


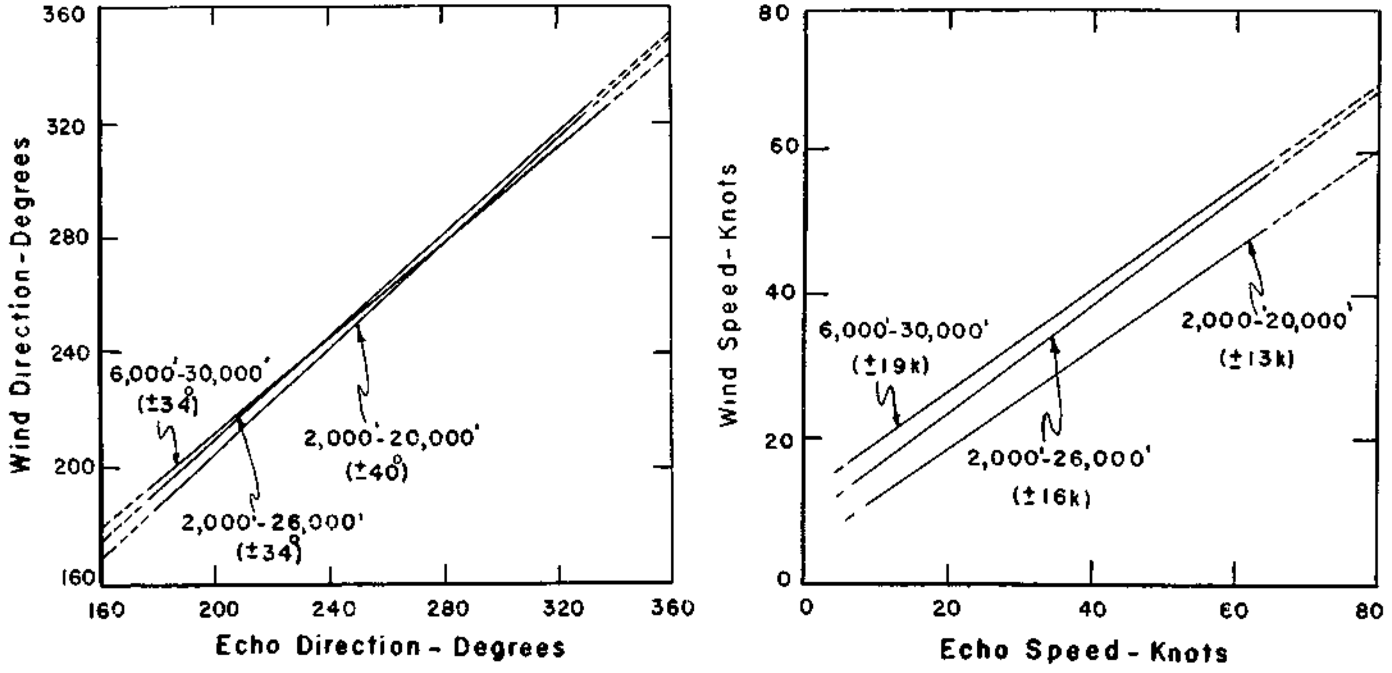
FIG.9 RADAR ECHO VS WIND FOR THREE LEVELS
ELEMENTS OF A SQUALL LINE

—— 1.1 LINE ——— REGRESSION LINE

SPECIFIC LEVELS

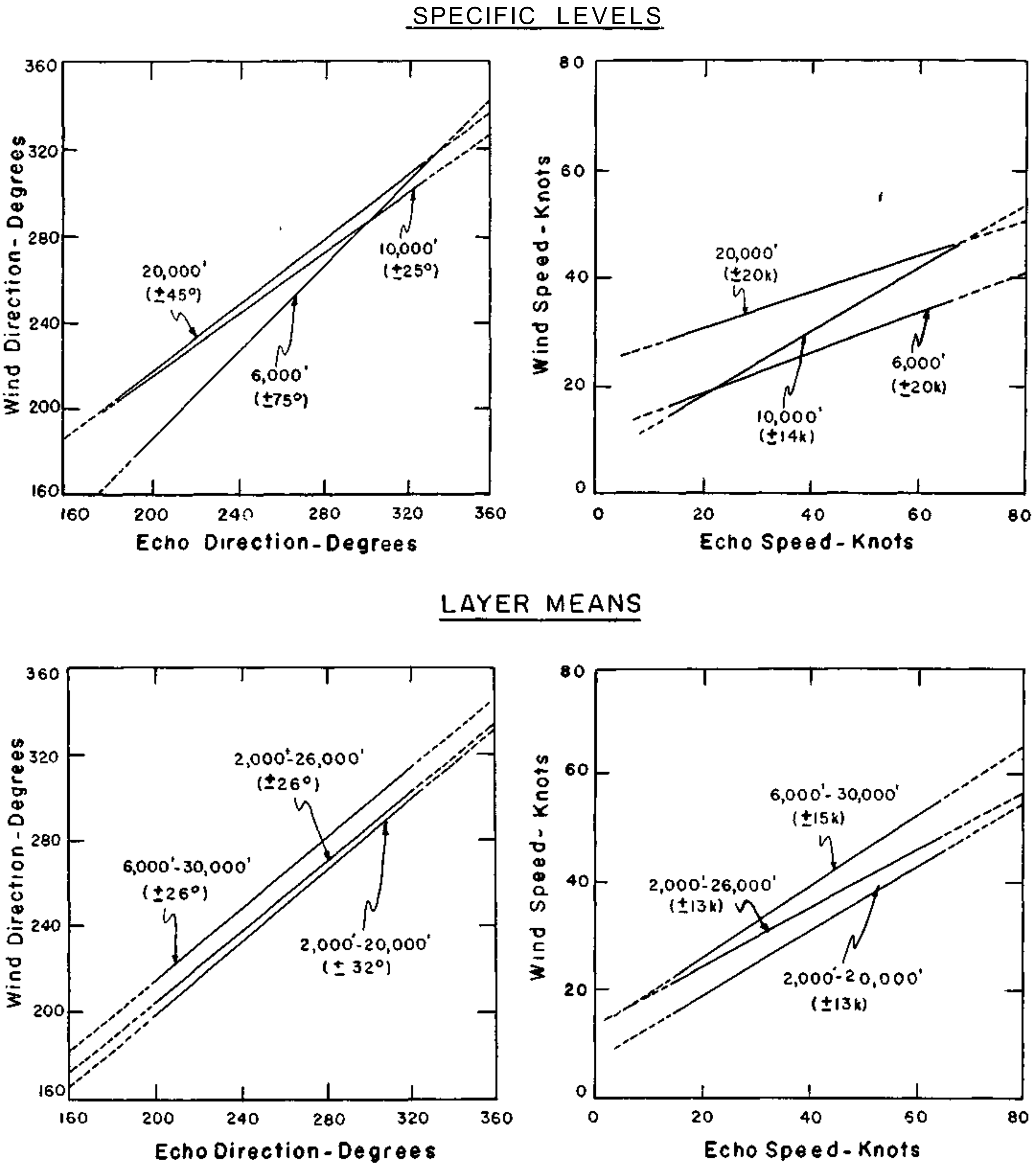


LAYER MEANS



NOTE: Bracketed Values = 95% Confidence Limits

FIG. 10 NOMOGRAMS FOR DETERMINING WINDS FROM ISOLATED ECHOES



SPECIFIC LEVELS

LAYER MEANS

NOTE: Bracketed Values = 95% Confidence Limits

FIG. II NOMOGRAMS FOR DETERMINING WINDS FROM ELEMENTS OF SQUALL LINES