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A COMPUTATION METHOD OF THE VELOCITY OF INDIVIDUAL ECHOES INSIDE HURRICANES

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ABSTRACT

By using the modified shifting technique, instantaneous velocities of individual echoes inside Hurricane Carrie were obtained. The result seems useful, making it possible to visualize the instantaneous movement of the convective cells circling around the storm center. In order to carry out this time-consuming computation more efficiently, a photographic method was developed. By this method, the modified shifting can be made photographically by using a gadget designed for the multiple exposure of echoes on 35 mm negatives.

1. INTRODUCTION

A shifting technique was used by the writer[1] for the purpose of computing the velocity of individual echoes photographed by a ground PPI radar.

In case radar pictures are taken by a moving vehicle, such as a hurricane research airplane, the ground velocity of the plane must be subtracted from the echo movement relative to the airborn radar in order to obtain the ground velocity of radar echoes. The following relationship should be applied:

$$\mathbb{v}_r = \mathbb{v}_g - \mathbb{V}_g$$

$$\text{or} \quad \mathbb{v}_g = \mathbb{v}_r + \mathbb{V}_g,$$

where $\mathbb{v}_r$ is the echo velocity relative to the airplane, $\mathbb{v}_g$ the ground velocity of the echo, $\mathbb{V}_g$ the ground velocity of the airplane. It is not practical, however, to compute a small vector quantity as a resultant of two large vectors.

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[1] Fujita: "Mesoanalysis of the Illinois Tornadoes of 9 April 1953," Journal of Meteorology, Vol. 15, No. 3, June, 1958, pp. 288-296.

Moreover, the time variation of the ground velocity of the airplane is so large that a test computation revealed that this method is unsatisfactory.

2. MODIFIED SHIFTING TECHNIQUE

Hurricane research airplanes are equipped with very accurate longitude and latitude indicators. As will be seen in Table 1, positions are reported with an accuracy of 0.1 min., or about one-tenth of a nautical mile.

Time	Latitude	Longitude
21 h. 50 min.	31 deg. 00.2 min.	60 deg. 04.2 min.
51	00.7	01.0
52	02.2	59 deg. 56.5 min.
53	04.0	52.2
54	06.0	48.2
55	07.2	46.2

Table I. Position of the hurricane research airplane which flew through Hurricane Carrie on September 15, 1957.

This is accurate enough to eliminate the effect of the change in location of the plane while taking radar pictures.

Let A_o, A_1, A_2 .... in Fig. 1 be the positions of an ariplane at one-minute intervals. The heading of the plane is shown by the arrows which deviate from the tangent to the plane's path indicated by a curved broken line. The location of a particular echo E, for example, changes from E_o to E_3 during the time in which the plane moves from A_o to A_3. One would expect that the plotted echoes would be congested, and that the identification of individual echoes is very difficult even if colors should be used in distinguishing them. This is quite true from a practical point of view.

By use of the shifting technique, the individual echoes, on a line or in an area, are separated in the direction of shifting. And this technique avoids the congestion of successive echo patterns; the direction and the amount of shifting are so determined as to separate individual echoes at the closest, but distinguishable, distance. The right-hand diagram in the figure shows the actual shifting processes. First, the plane's positions A_0, A_1, A_2 .... are shifted eastward as much as 0x, 1x, 2x .... respectively, and then the positions of echo E, relative to the new positions of the airplane indicated by A_0', A_2' ...., are plotted on the chart. The successive positions of the echo will thus appear as E_0, E_1', E_2' ...., enabling them to be separated from each other.

A line connecting a corresponding portion of the successive echo pattern may be termed the "echo identification line." The shifted positions of the echo along this line are again shifted backward and the echo movement relative to the earth's surface is obtained.

3. ANALYSIS OF HURRICANE CARRIE OF SEPTEMBER 15, 1957

Seen in Fig. 2 is the analysis of Hurricane Carrie whose center at 2159 EST was located about 31 N and 60 W. The hurricane research airplane flew through the eye from southwest to northeast. A long rainband located at about 40 nautical miles east of the eye was used in constructing this chart, and the shapes of the echoes were copied at one-minute intervals while the position of the airplane was shifted as much as 15 nautical miles per minute. Corresponding portions of the echoes in the rainband were connected by the echo identification lines; then the positions of each echo along these lines were shifted back in order to obtain the actual positions indicated by the black dots. Echo velocities thus computed are represented by the wind symbols.

It may be noted that the observed wind velocities at 14,000 ft., the flight level, are very close to the velocities computed by using this technique. It is very likely that the steering level of these rainband echoes is the level of this particular flight.

The ground velocities of the individual echoes on and outside the eye wall of Hurricane Carrie were computed. The result presented in Fig. 3 shows that the eye wall, some 40 nautical miles in diameter, is rotating at the rate of about 70 kts, enabling it to make one complete revolution in one hour and 50 minutes -- the rate of about three degrees per minute.

The radial component of the echo velocity relative to the hurricane center was determined. The result tabulated in Table II indicates that the radial component ranges between +27 (outward) and -17 kts (inward).

Echo	r (N.M.)	dd (deg.)	vv (kts)	ω (deg/min)	φ deg.	C_n (kts)
A	15	271	90	5.6	+13	+20
B	20	262	91	4.3	+3	+5
C	16	235	79	4.5	+17	+22
D	17	168	63	3.3	+17	+19
E	17	145	62	3.1	+27	+27
F	20	081	64	2.9	+17	+19
G	20	040	70	3.3	-12	-14
H	24	023	61	2.4	-7	-7
I	21	017	57	2.6	+3	+4
J	16	349	59	3.5	-12	-13
K	25	345	64	2.4	-7	-7
L	19	328	76	3.8	-9	-13
M	9	258	85	8.7	-12	-16
N	42	202	79	1.8	+2	+2
O	40	190	81	1.9	+13	+18
P	39	152	64	1.6	+7	+7
Q	62	140	63	1.0	-2	-3
R	42	128	60	1.4	+10	+10
S	56	104	65	1.1	-12	-13
T	50	095	70	1.3	-3	-5
U	50	073	70	1.3	-12	-13
V	46	340	60	1.2	-10	-10
W	46	320	61	1.2	-12	-13
X	51	307	60	1.1	-17	-17

Table II. The relative velocity of individual echoes with respect to Carrie's center. r denotes the distance from the hurricane center; dd, the direction of echo movement; vv, the speed of echo relative to the center; ω, angular velocity of echo; φ, crossing angle showing inflow (-) and outflow (+); and C_n, the radial component of relative echo velocity.

It is of extreme interest to see the organized pattern of the radial component of the relative echo velocity shown in Fig. 4. The areas of outgoing and incoming echoes are clearly separated by a line of zero radial echo velocity. This line may be called "echo convergence line" or "echo divergence line" depending upon the direction of the radial echo velocities which are directed toward or away from the line.

Actually, as seen in Fig. 4, Hurricane Carrie was accompanied by a pronounced echo convergence line to the north of her center. It is expected that this line tends to bring echoes in such a position that they collide with each other, resulting probably in a new development of convective activity along the line. On the other hand, the eye wall south of the echo divergence line was moving outward from the center, while the eye wall to the north of that line was moving inward. A penetration of this storm made by the hurricane research airplane about one hour later revealed that the eye wall was wide open, showing that the echoes on both sides of the echo divergence line kept moving in opposite radial directions.

4. PHOTOGRAPHIC METHOD

Presented in this chapter is a photographic method by which the modified shifting technique can be accomplished without time-consuming work.

The gadget shown in Fig. 5 consists of a photographic paper-holder attached to a sliding bar, capable of sliding toward the left at any shifting interval required. A metal plate with two transparent plastic windows is fixed to the gadget base with two hinges, enabling it to open when the photographic paper fixed on the sliding bar is placed beneath it. Figure 6 shows the open position of the plate.

Operation of the gadget is simple: first we transcribe the plane's positions, at one-minute intervals, for instance, on the left-hand plastic window; then the paper is exposed through this window while the other is covered; next, the radar echoes are printed through the right-hand window after placing the center of each radar picture exactly at the plane's position on the left-hand window. During this process, the photographic paper whould be shifted leftward at a constant rate after each exposure.

When all exposures are finished, the paper is developed immediately. The print thus obtained is to be used for the computation of individual echo velocities. Figure 7 shows an example of the developed paper.

CONCLUSION

It has become possible, by using the modified shifting technique, to compute instantaneous echo velocities with an appreciable accuracy. A test computation of the Hurricane Carrie case indicated that the individual echoes on or outside the eye wall are moving either outward or inward. However, the areas of outgoing and incoming echoes are well organized, suggesting that such areas are probably persistent. Further studies of this type will be extremely important in clarifying the mesoscale structure of hurricane rainbands.

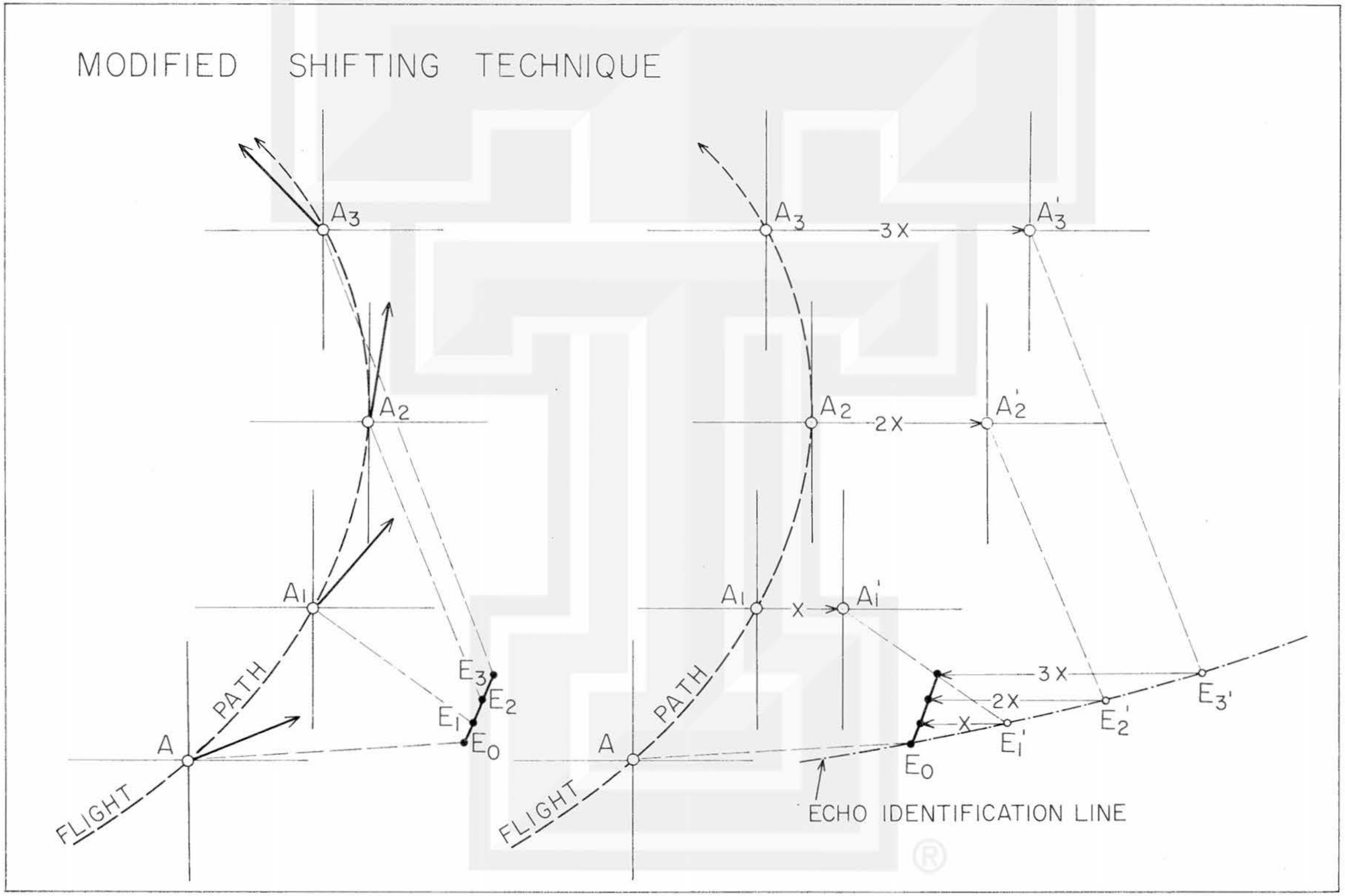
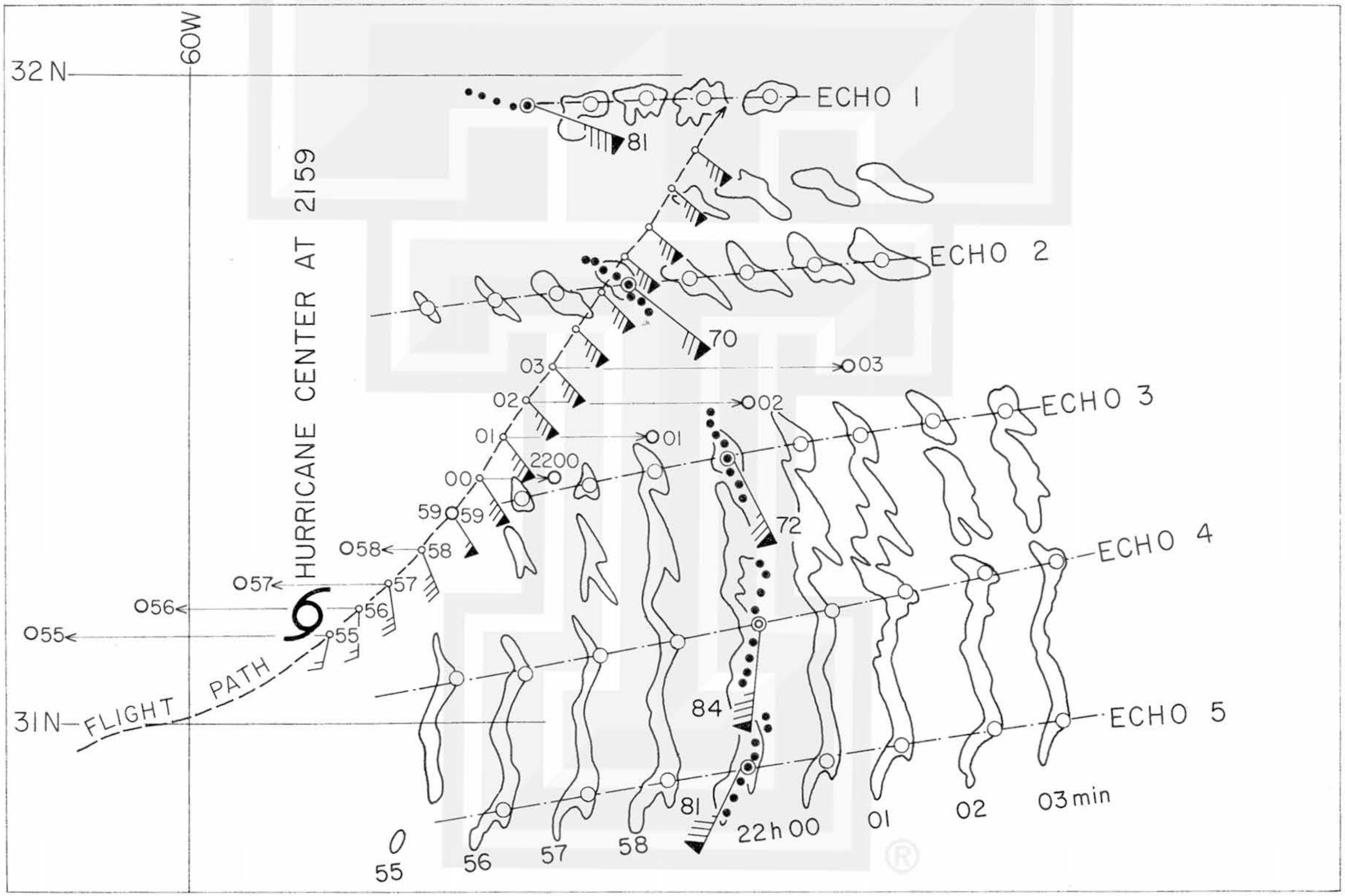

MODIFIED SHIFTING TECHNIQUE
FLIGHT PATH
A
A1
A2
A3
E0
E1
E2
E3
X
2X
3X
A1'
A2'
A3'
E1'
E2'
E3'
ECHO IDENTIFICATION LINE

FIG. 1



32 N
31 N
60W
HURRICANE CENTER AT 2159
FLIGHT PATH
ECHO 1
ECHO 2
ECHO 3
ECHO 4
ECHO 5
81
70
72
84
81
03
02
01
2200
00
59
58
57
56
55
55
56
57
58
22h00
01
02
03 min

FIG. 2

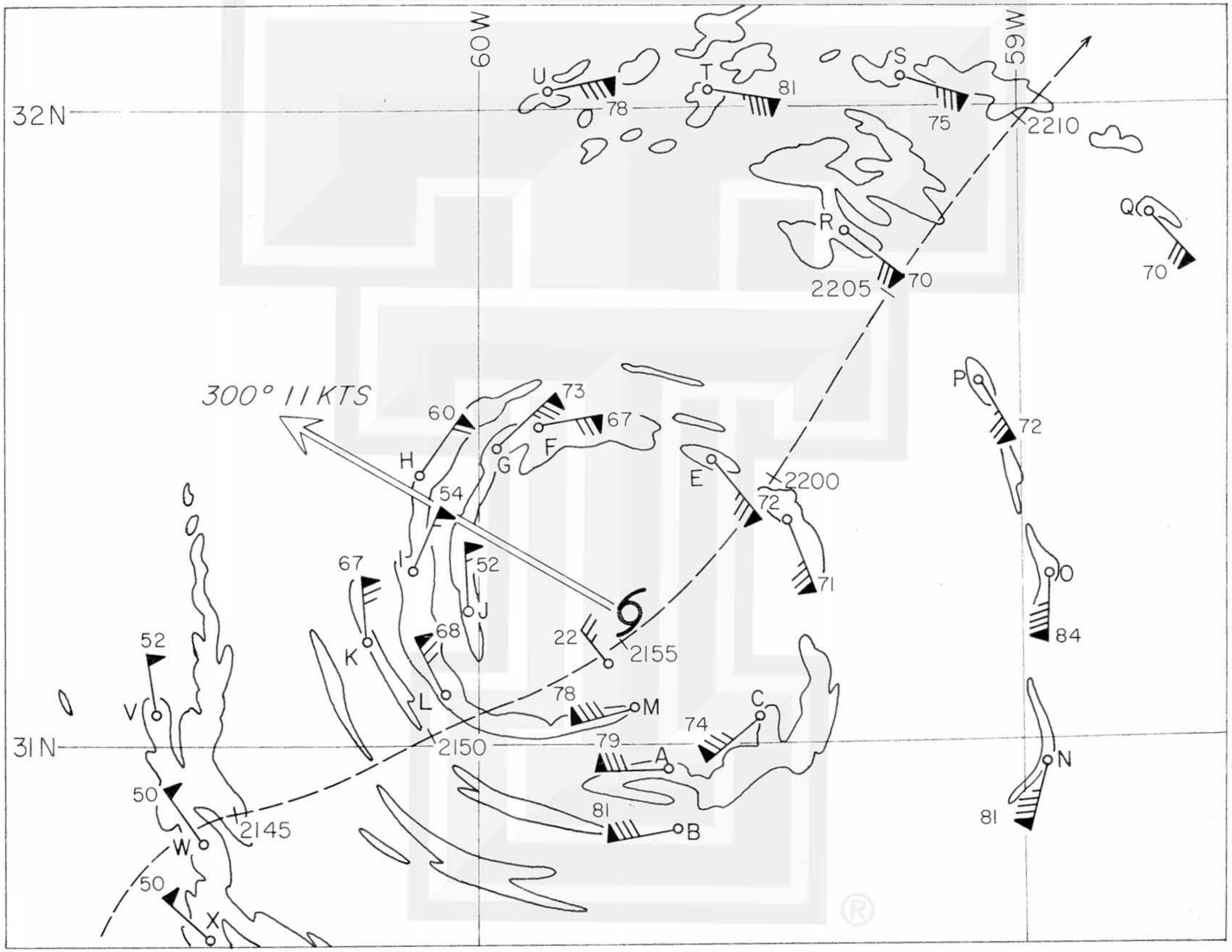

300° 11 KTS
32N
31N
60W
59W
2145
2150
2155
2200
2205
2210
A
B
C
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
78
81
75
70
70
73
67
60
54
52
67
68
22
72
71
72
84
81
78
79
74
81
52
50
50

FIG. 3

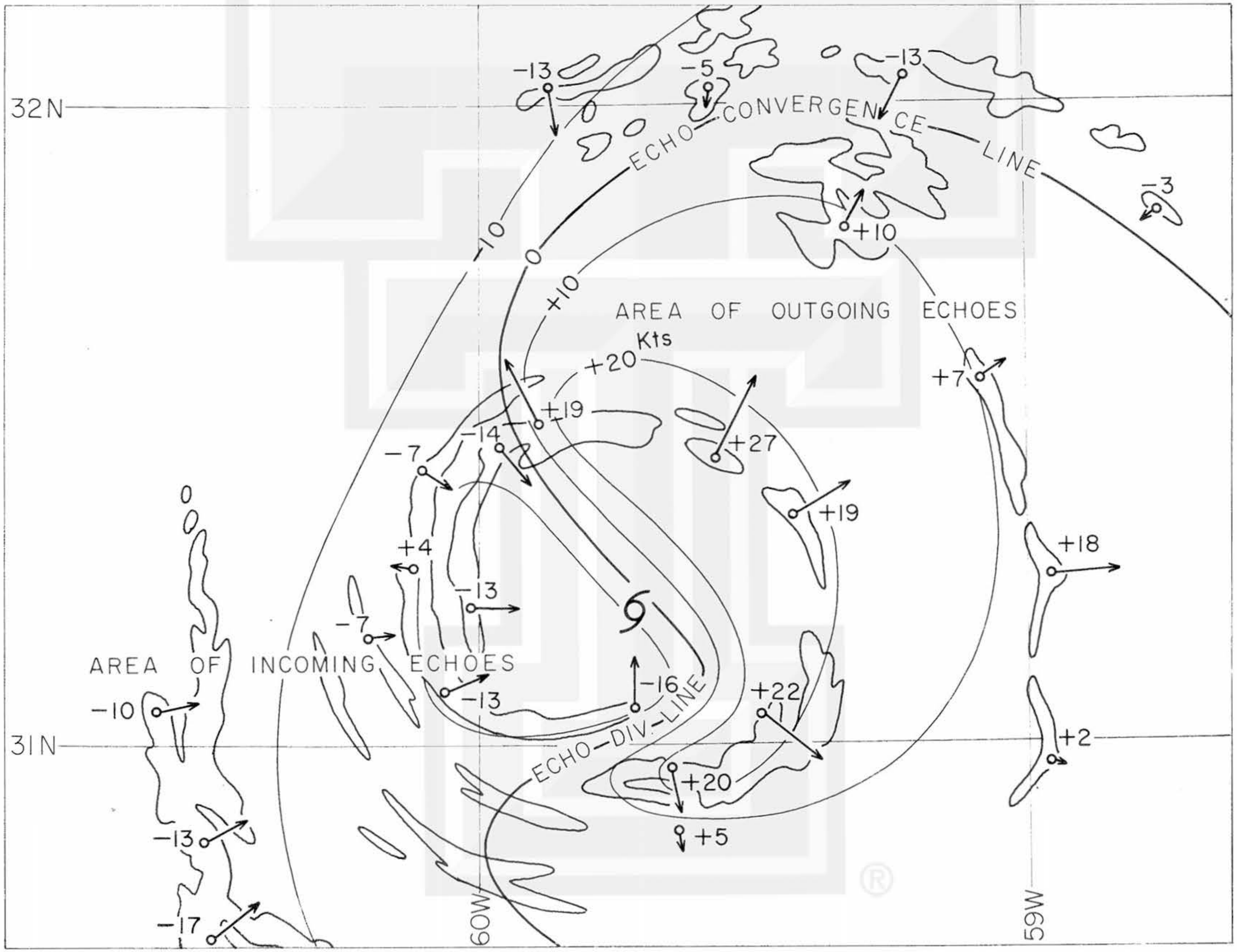

32N
31N
60W
59W
ECHO CONVERGENCE LINE
ECHO-DIV-LINE
AREA OF OUTGOING ECHOES
AREA OF INCOMING ECHOES
Kts
-10
0
+10
+20
-13
-5
-13
-3
+10
+7
+19
+27
-14
-7
+19
+18
+4
-13
-7
-16
+22
-13
-10
+2
+20
+5
-13
-17

FIG. 4