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An investigation of the movement of the 24 hour isallohyptic centers at 700 mbs

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by

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PREFACE

The purpose of this research was to examine the effect of the 500 mb winds on the steering of the isallohyptic centers at 700 mbs.

This study was conducted at the U. S. Naval Postgraduate School, Monterey, California during the period from December 1948 to May 1949.

The topic was suggested by Professor Frank L. Martin. The author wishes to express his appreciation to Professor Martin for his helpful advice and guidance in the preparation of this paper.

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TABLE OF SYMBOLS

U_t	24 hour eastward movement of the 700 mb height tendency center
V_t	24 hour northward movement of the 700 mb height tendency center
u	Eastward component of the 500 mb geostrophic wind
v	Northward component of the 500 mb geostrophic wind
T	24 hour tendency of the 700 mb height tendency center
r	Correlation coefficient
σ	Unit of standard deviation

CHAPTER I

INTRODUCTION

In order to prognosticate accurately the contours on the 700 mb pressure surface by the height tendency method, it is essential to determine accurate rules governing the movement of the centers of rising and falling height tendency on the given surface. Very little is known about the movement of these centers apart from the general kinematic principle of extrapolation based on the path method described in (4). However, application of the path method has the following defects:

(a) uncertainty as to the initial position of the tendency centers as they enter the west coast of North America.

(b) at least two daily positions of the 24 hour tendency centers should be available to delineate the paths adequately; however, in numerous forecast offices the necessary number of analyzed charts is not available.

(c) there is not sufficient history for an accurate extrapolation of tendency centers in the western half of North America unless further empirical rules are discovered.

It is therefore the object of this dissertation to determine empirical rules governing the movement of the 700 mb tendency centers.

Let the eastward and northward components of the 24 hour movement of the 700 mb tendency center be denoted U_t, V_t respectively. These velocity components will be correlated statistically with certain variates observable on the upper level charts. Specifically regressions of the form

$$U_t = a_1 u + a_2 v + a_3 T + a_4 \quad (1)$$

$$V_t = b_1 u + b_2 v + b_3 T + b_4 \quad (2)$$

are investigated where u, v are the eastward and northward geostrophic wind components over the tendency center at the 500 mb level, and T is the 24 hour tendency of the tendency center.

Obviously the inclusion of u in (1) and v in (2) are for the purpose of determining the influence of advection on the steering of the tendency field. The question of steering sea level cyclones by the upper air circulation has been investigated by many writers; e.g., Runk (7), Austin (1), Longley (5), etc., and the problem of steering of tendency centers was approached as the analogue of these earlier solutions. Strictly speaking, then, a complete investigation of steering of tendency centers should consider the geostrophic or thermal wind components from all significant levels up to and including the 100 mb surface. While the 300, 200 and 100 mb charts were not available for the period considered, it was felt that at least an indication of steering by the 500 mb geostrophic winds would be revealed.

The inclusion of the northward component v in the right side of (1) is for the purpose of testing this variate as an index of the divergent contribution of the velocity of the tendency center. This is suggested by Petterssen*, a northward (positive) component of the gradient wind being associated with convergence, southward with divergence. Purely from considerations of symmetry, rather than by theoretical justification, a component u has been incorporated into the equation (2) for V_t.

*Weather Analysis and Forecasting - p. 229

The 24 hour tendency, T, of the 700 mb tendency centers both in (1) and (2) is another possible index of the divergent contribution to the velocity of the tendency center. For example, if a negative tendency center deepens, indicating divergence aloft, it is felt that this should influence both velocity components of the tendency center.

Note that no circulation variates for the 700 mb level or below have been included, the assumption being made that steering of any tendency pattern will be due primarily to circulation above the level in question. However, the variate, T, which is not a circulation variate does apply to data on the 700 mb surface.

The data for this work were obtained from the "Northern Hemisphere Historical Weather Maps", Sea Level and 500 mb Charts (8). Each volume of the series consists of a full month of individual daily sea level charts (1230 GCT) and of daily 500 mb charts (0400 GCT) for the entire northern hemisphere. Each volume also includes, in addition to the analyses, a complete set of teletype reports.

In (8), the 500 mb surface maps have been analyzed at 0400 GCT because more data were available at that time. Also each map was analyzed a sufficiently long time after the receipt of the map data to allow for the use of late reports, etc. Because of this it was decided to use this series of analyzed charts in determining the 500 mb winds in spite of the disadvantage of its small scale.

The data examined was that of March and April, 1946. Negative tendency centers were considered separately from positive centers. The components of movement of these centers were then correlated with the variates u, v, and T of equations (1) and (2), the data for u, v being taken from the 500 mb chart directly over the 700 mb tendency center in accordance with the usual steering concepts. The variate T was obtained for each center by obtaining the difference between the previous days central tendency isoline and that of the current value of the tendency center.

The results indicate fairly definite correlation of the movement of the positive tendency centers with the 500 mb flow, but for the negative tendency centers essentially zero correlation was obtained for the particular independent variates selected. A discussion of the results is given in Chapter III.

CHAPTER II

ANALYSIS AND RESULTS

1. Procedure

The period of this investigation was chosen to begin on 1 March 1946 and terminate on 30 April 1946. The charts used for the above period were:

a. 0400 GCT 500 mb constant pressure surface

b. 1930 EST sea level surface

c. 700 mb height tendency centers

The 500 mb charts were obtained from (8). The 1930 EST sea level maps were analyzed by the Aerological Staff at the U. S. Naval Postgraduate School. The U. S. Weather Bureau Daily Weather Maps (surface) were also used. The 700 mb height tendency charts were drawn and analyzed. The height tendencies for this paper were taken from the teletype sequence data of (8).

The tendency field could have been obtained in one of the following two ways:

a. By drawing a differential analysis between the 700 mb contours of the day in question and that of the preceding day. This is common practice in many meteorological offices.

b. As obtained for this study the height of the 700 mb surface was obtained from the teletype sequence (8). The height of the 700 mb surface was recorded for every radiosonde station in the U. S., Canada, Alaska, the Aleutian Islands, Mexico and the Caribbean Area. The difference in the height of the 700 mb surface between two days is the height tendency for the particular day in question.

The latter method was used since it was felt that the final location of the tendency centers would be considerably more accurate. In an attempt to locate tendency centers as accurately as possible, isolines of tendency were drawn for every hundred foot interval instead of the conventional two hundred foot intervals. In several cases where the gradient of the tendency was weak, these additional lines were of considerable help.

The tendency centers selected for the correlation analysis were enclosed by at least one height tendency line and in most cases by several. Only those centers were used which had an adequate number of reports to guarantee a good degree of accuracy in locating the position of the centers. Satisfying these criteria, there were 50 distinct cases of negative tendency centers and 51 of the positive centers.

The data recorded were as follows:

a. The twenty-four hour movement of the tendency center was obtained and broken down into a west-east component of movement (U_t) and a south-north component of movement (V_t) measured in nautical miles.

b. The position of the isallohyptic center was marked on the 500 mb constant pressure surface and the geostrophic wind components measured at this point. The eastward (u) and northward (v) components were measured in knots.

c. The twenty-four hour tendency of the tendency center (T) was recorded. To permit a little more sensitivity in this variate the tendency was measured to the closest fifty feet.

2. Results

The variates listed above are used for the analysis of both the positive and negative isallohyptic centers. In the analysis for positive tendency centers, simple correlations were calculated between U_t and the other three variates; also between V_t and the same three variates. The arithmetic means, standard deviations (σ), and correlation coefficients have been tabulated below for each case.

The units of U_t, V_t are in tens of nautical miles per day; while those of u, v are knots, T in tens of feet per day.

	Arithmetic means	Standard deviations	Simple correlation coefficients		
			$r(U_t, -)$*	$r(u, -)$	$r(v, -)$
U_t	48.33	19.80	-		
u	26.96	14.22	0.586		
v	-17.63	20.21	0.165	0.221	
T	4.22	15.84	0.231	0.227	0.098
			$r(V_t, -)$	$r(u, -)$	$r(v, -)$
V_t	-9.02	28.39	-		
u	26.96	14.22	0.489		
v	-17.63	20.21	0.406	0.221	
T	4.22	15.84	0.386	0.227	0.098

TABLE I

Simple correlation analysis for positive tendency centers

* In $r(U_t, -)$, the dash indicates the simple correlation is taken with respect to U_t and the variate appearing in the same row of the table

The Multiple Correlation Analysis follows:

The multiple correlation coefficients are:

$$r_{U_t} \cdot uvT = 0.595$$

$$r_{V_t} \cdot uvT = 0.6344$$

The regression equations are:

$$U_t = .99u + .031v + .127T + 21.57$$

$$V_t = .715u + .417v + .489T - 23.04$$

The standard error of estimates are:

$$S_{U_t} \cdot uvT = 15.92 \text{ or } 159 \text{ nautical miles}$$

$$S_{V_t} \cdot uvT = 21.95 \text{ or } 219 \text{ nautical miles}$$

Scatter diagrams indicating the relationship between the components of motion of the positive tendency centers and wind components on the 500 mb surface and T are shown in Figures 1 through 6. These figures follow the tabular results at the end of the chapter.

The correlation coefficient between U_t and V_t was found to be 0.406.

A correlation analysis was attempted for only those cases for which $u > 20$ knots. There were 39 cases in this subclassification. The object was to see if restricting the analysis to those cases for which at least a moderate west wind component existed gave significantly better results. The results are as follows:

	Arithmetic means	Standard deviations	Simple correlation coefficients
			$r(U_t, -)$
U_t	54.85	14.66	-
u	33.28	8.07	0.0684
v	-14.67	21.53	-0.00912
T	7.05	14.62	-0.0225
			$r(V_t, -)$
V_t	- 1.85	25.89	-
u	33.28	8.07	0.362
v	-14.67	21.53	0.342
T	7.05	14.62	0.265

TABLE II

Simple correlation analysis for positive tendency centers; $u > 20$ knots

The simple correlation coefficients resulting from the above subdivision were not improved significantly over those in Table I, so that a separate regression analysis was not considered to be warranted.

A similar procedure was followed for the negative tendency centers. Table III shows the simple correlation analysis for all cases of negative isallohyptic centers.

	Arithmetic means	Standard deviations	Simple correlation coefficients
			$r(U_t, -)$
U_t	45.12	16.995	-
u	36.20	18.449	0.116
v	24.92	26.285	-0.0433
T	-5.5	24.192	0.0449
			$r(V_t, -)$
V_t	2.0	28.15	-
u	36.20	18.449	-0.0272
v	24.92	26.285	0.405
T	-5.5	24.192	-0.421

TABLE III

Simple correlation analysis for all negative tendency centers

Since the simple correlation coefficients of U_t on u, v and T for the negative centers were poor it was thought that perhaps too many of the cases tested were quasistationary on the sea level maps. Further correlations were therefore computed for only those cases where the corresponding sea level low centers had west-east movements in excess of 200 nautical miles per day. Table IV contains the results obtained for the 38 cases tested.

	Arithmetic means	Standard deviations	Simple correlation coefficients
			$r(U_t, -)$
U_t	47.474	16.877	-
u	35.579	19.650	0.236
v	26.842	27.355	-0.0511
T	-7.105	22.496	-0.0819
			$r(V_t, -)$
V_t	6.053	28.153	-
u	35.579	19.650	0.124
v	26.842	27.355	0.525
T	-7.105	22.496	-0.360

TABLE IV

Simple correlation analysis for negative centers with corresponding sea level movements in excess of 200 nautical miles

Similarly to the case for positive centers, a simple correlation analysis was computed for the negative centers for only those cases where $u > 20$ knots. These results are contained in Table V. There were 41 cases available in this subclassification.

	Arithmetic means	Standard deviations	Simple correlation coefficients
			$r(U_t, -)$
U_t	45.78	17.354	-
u	41.049	16.801	0.0734
$\bar{v}$	27.024	26.046	-0.00654
T	-6.829	26.033	-0.0126
			$r(V_t, -)$
V_t	1.341	29.173	-
u	41.049	16.801	0.00817
$\bar{v}$	27.024	26.046	0.403
T	-6.829	26.033	-0.419

TABLE V

Simple correlation analysis for negative tendency centers with u > 20 knots

Here again the simple correlation coefficients for U_t on u, $\bar{v}$ and T were so poor that it was considered inadvisable to calculate the regression equations and the standard error of estimates.

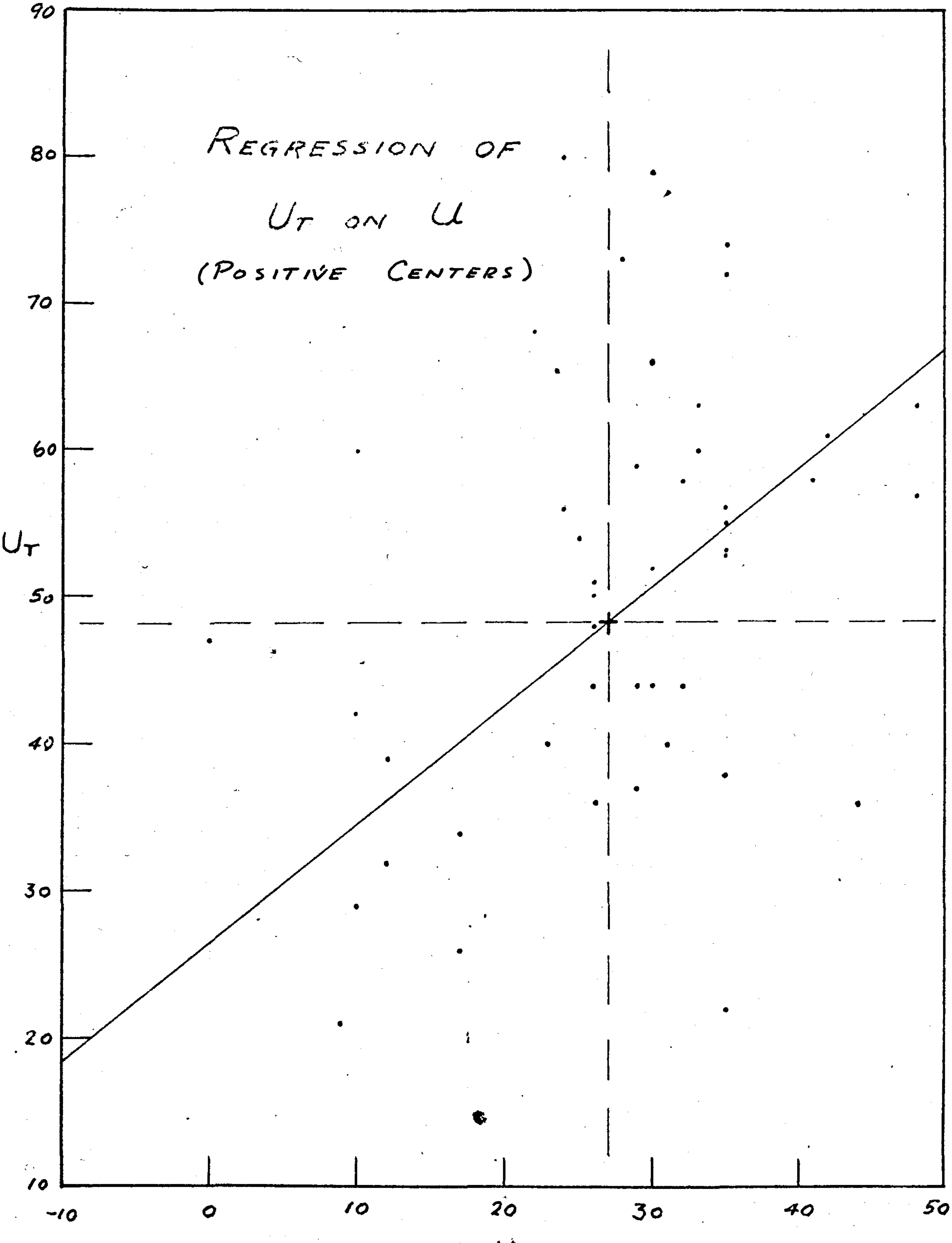
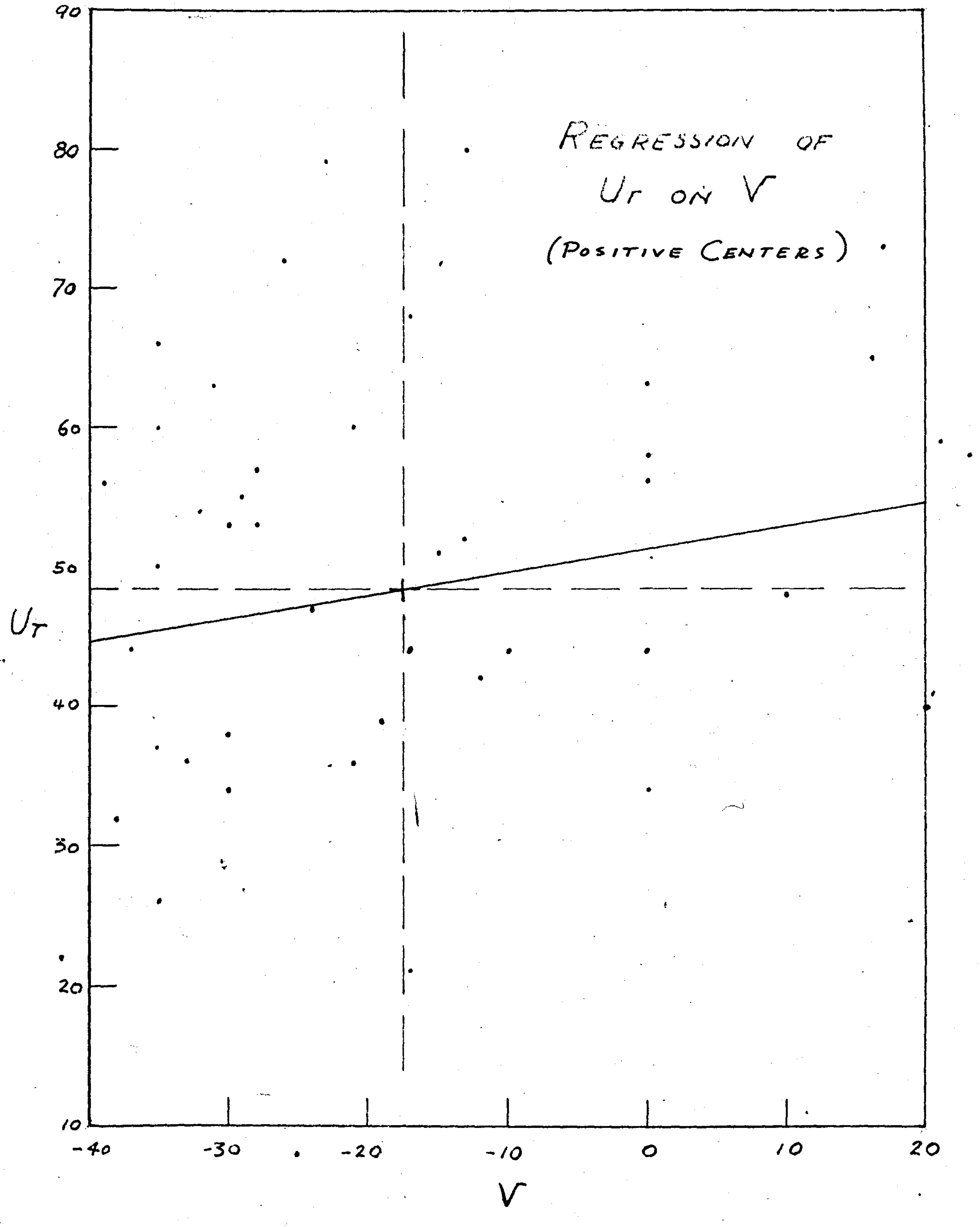

REGRESSION OF
U_T ON U
(POSITIVE CENTERS)
U_T
U
90
80
70
60
50
40
30
20
10
-10
0
10
20
30
40
50

FIG. 1



REGRESSION OF
U_T ON V
(POSITIVE CENTERS)
90
80
70
60
50
40
30
20
10
U_T
-40
-30
-20
-10
0
10
20
V

FIG. 2

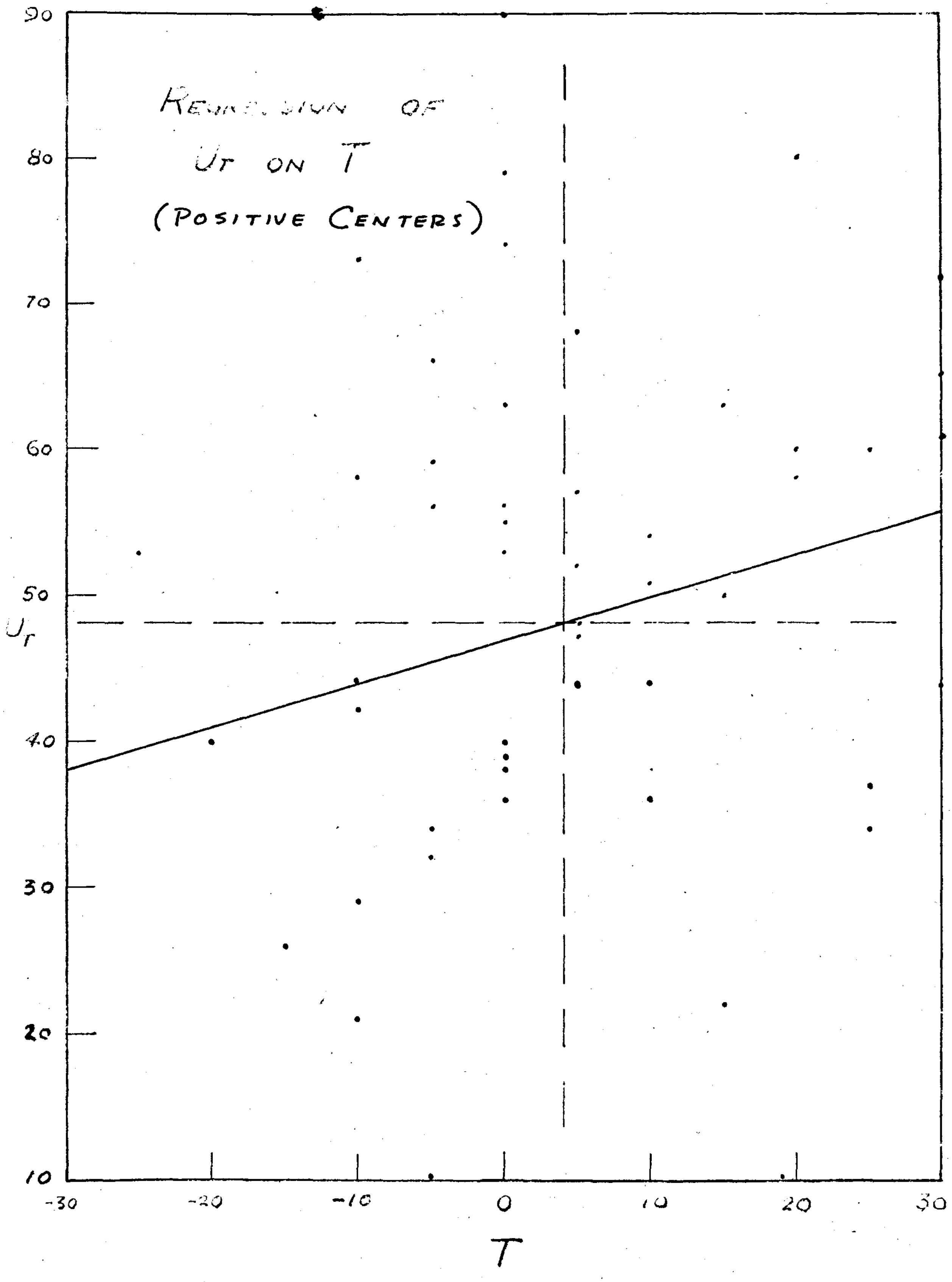

REGRESSION OF
U_T ON T
(POSITIVE CENTERS)
90
80
70
60
50
40
30
20
10
U_r
-30
-20
-10
0
10
20
30
T

FIG. 3

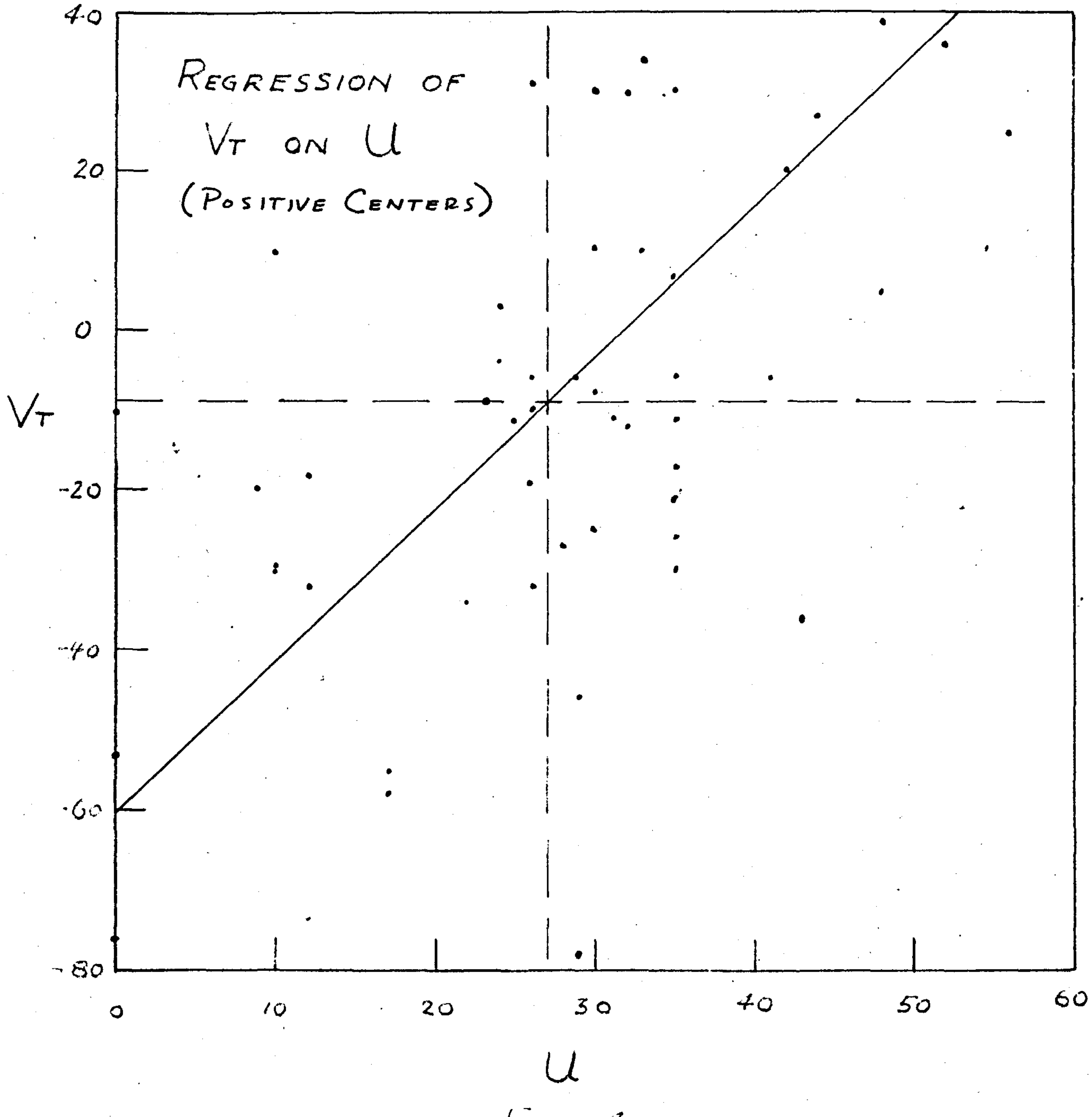

REGRESSION OF
VT ON U
(POSITIVE CENTERS)
40
20
0
-20
-40
-60
-80
VT
0
10
20
30
40
50
60
U

FIG. 4

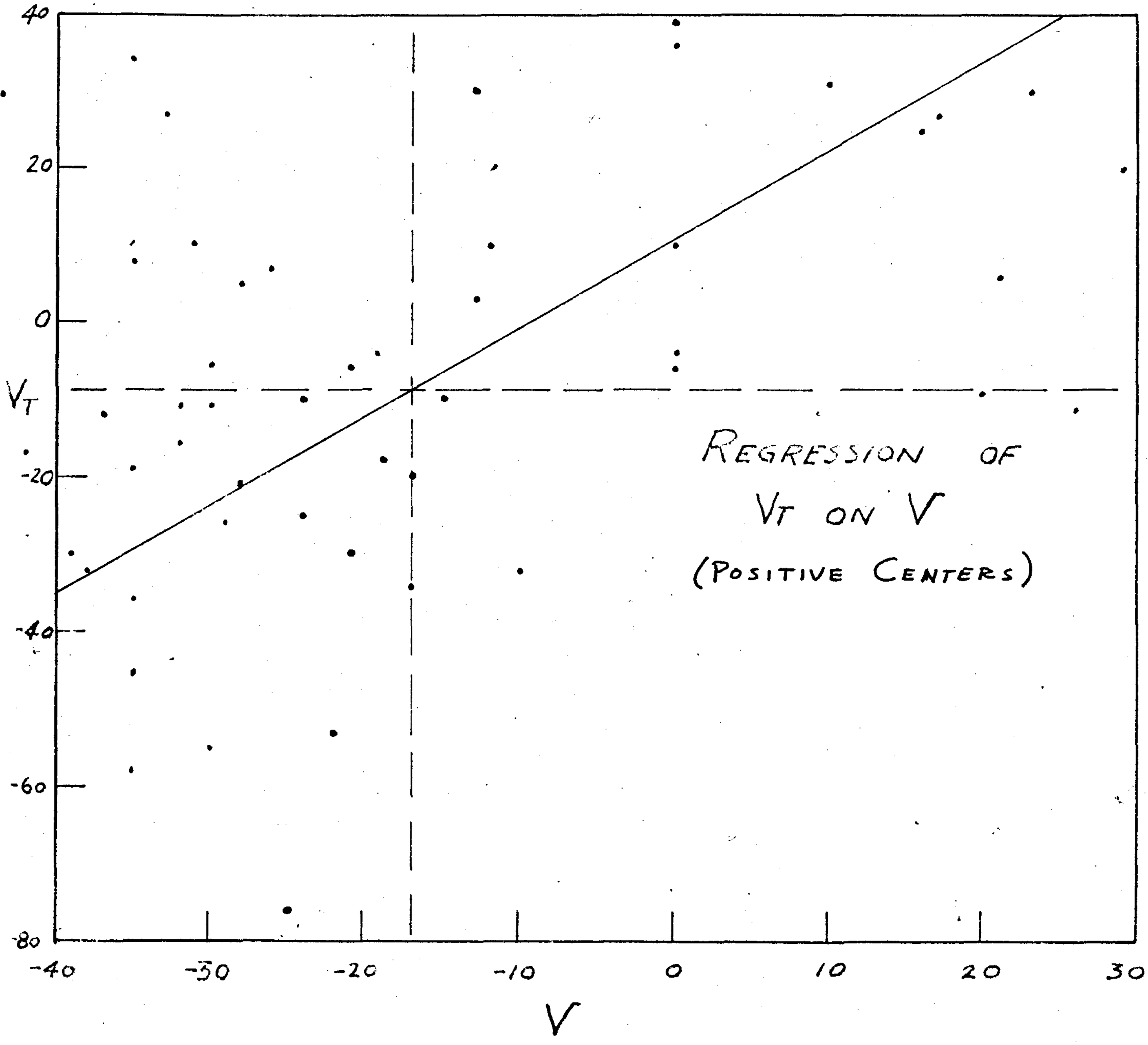

40
20
0
-20
-40
-60
-80
V_T
-40
-30
-20
-10
0
10
20
30
V
REGRESSION OF
V_T ON V
(POSITIVE CENTERS)

FIG. 5

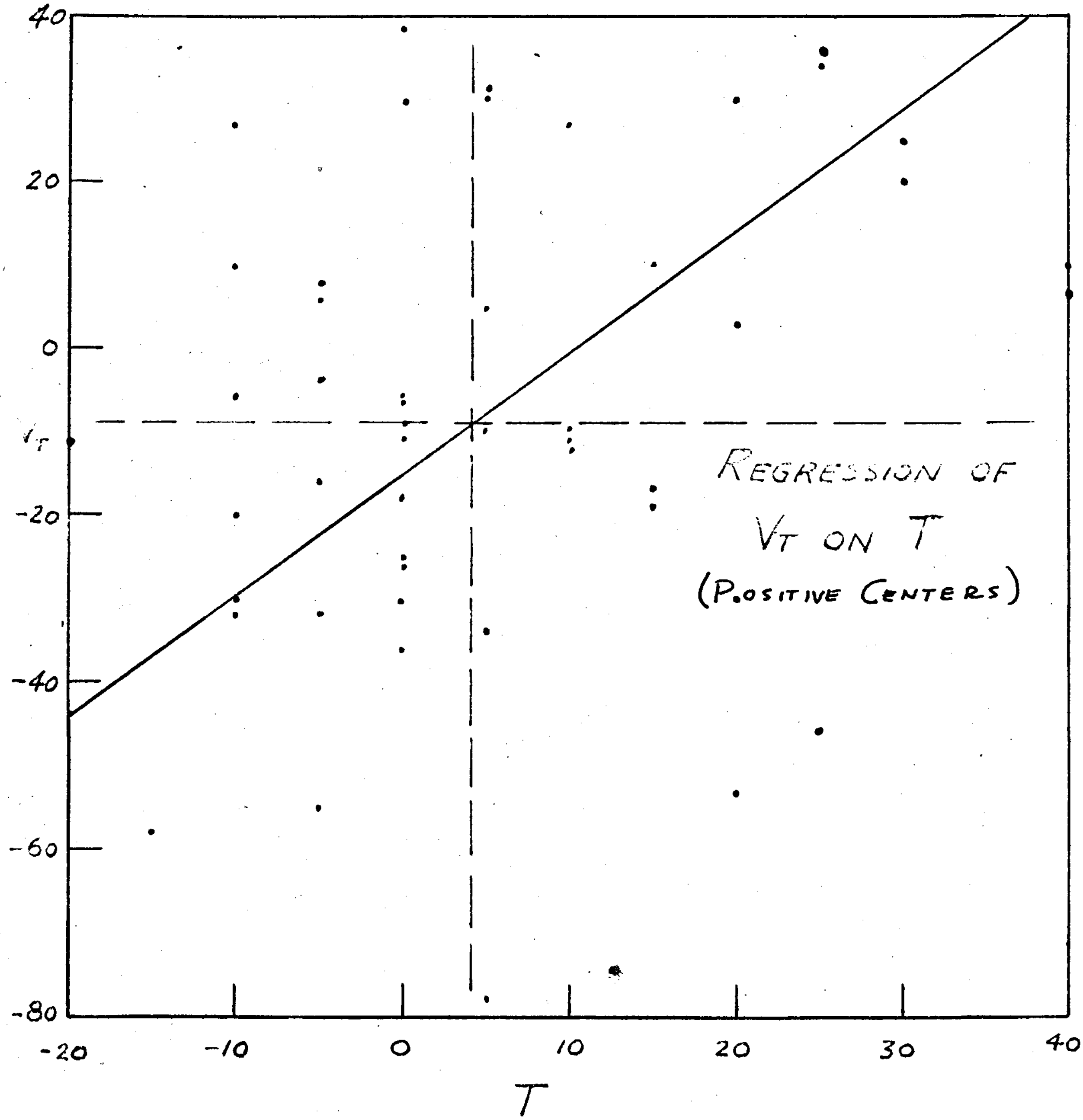

40
20
0
V_T
-20
-40
-60
-80
-20
-10
0
10
20
30
40
REGRESSION OF
V_T ON T
(POSITIVE CENTERS)
T

FIG. C

CHAPTER III

CONCLUSIONS

Considering first the results for positive tendency centers, examination of Table I indicates that all simple correlation coefficients are positive. The results for the eastward movement of the positive tendency centers indicates very little dependence on the northward geostrophic wind component, v, in view of the very small correlation coefficient, 0.17 existing between these two variates. The correlation coefficient $r(U_t, T) = .23$ indicates that T has slight influence on U_t. The largest simple correlation $r(U_t, u) = .59$ shows that u is the significant variate. This will also be seen from the regression equation.

For the northward movement V_t of the positive tendency centers, Table I indicates a correlation $r(V_t, u) = .49$, larger than $r(V_t, v) = .41$. No immediate explanation is available for this rather surprising result, except that the v components of velocity were more difficult to measure accurately. Also the v components were subject to considerable change during the 24 hour period, whereas in this study the component winds at the beginning of each period were used.

From the correlation coefficient $r(V_t, T) = .386$, one would expect an increasing V_t with an increasing T. This indicates that a positive tendency, T, of the positive tendency center, is associated with an increasing northward velocity, while a negative tendency T is associated with a decreasing northward velocity. This is consistent with the concepts of dynamic anticyclogenesis and blocking action which occur at latitudes 55-60°, the northward limit of the centers investigated in this study.

The multiple correlation coefficients for U_t and V_t on the three independent variates are 0.595 and 0.634. This indicates that the 500 mb level itself is not sufficient to provide the forecaster with an effective steering tool for positive tendency centers, and that variates from the higher pressure surfaces mentioned in the introduction are also necessary.

The regression equations derived in this study are:

$$U_t = .99u + .031v + .127T + 21.57 \qquad (3)$$

$$V_t = .715u + .417v + .489T - 23.04 \qquad (4)$$

where U_t, V_t are in tens of nautical miles, u, v in knots, and T in tens of feet. Equation (3) shows very weak sensitivity to v and T while (4) shows moderate sensitivity to v and T and greatest sensitivity to u. The standard error of estimates of U_t and V_t are 160 and 220 nautical miles per day.

Considering next the results for the negative tendency centers Table III indicates that all simple correlations involving U_t are weak. However, those of V_t on v and T are considerably better. These correlations were $r(V_t, v) = .41$ and $r(V_t, T) = -.42$. These state in effect that a deepening tendency center (T decreasing) is associated with an increasing V_t, which, in turn is associated with an increasing v (that is, increasing northward component). These results indicate that most of the cases of deepening tendency centers encountered in this study were associated with waves in the southerly flow on the forward side of quasi-stationary troughs in the westerlies.

The further correlation analyses for the negative tendency centers satisfying the criteria

(a) There is a corresponding sea level center which moved more than 200 nautical miles per day, and

(b) The eastward geostrophic wind component at 500 mb was in excess of 20 knots,

gave no improvement in the results.

A significant result of this study is the moderate success of the correlation analysis based on the 500 mb steering for positive tendency centers, and the lack of success for negative centers. A possible explanation is to be found in the level of non-divergence. Charney (2) points out that the 600 mb level normally ascribed to the surface of non-divergence results when one uses the February mean zonal wind in place of the actual winds aloft. However, with instability in the waves in the westerlies, there is

> no longer a constant level at which divergence vanishes; rather the divergence vanishes along an inclined surface. In fact with slight instability the major part of the surface of non-divergence is nearly horizontal and is to be found between 350 and 400 mb.*

In this connection it was noted early in this study that for the period considered there were numerous closed low centers on the 500 mb chart. For this type of situation it is logical that the height of the non-divergence level would be higher than for the case of a young developing wave. It seems likely therefore that the 500 mb level was alternately above and below the level of non-divergence for the cyclonic systems dealt with.

*p. 138-139 of (2)

For positive tendency centers, apparently this difficulty was not encountered to the same degree. From this it is possible to conclude that the level of non-divergence lies more consistently above or below the 500 mb level than was the case for the negative tendency centers. Of the two possibilities, just mentioned, it seems more likely that the 500 mb level is below the level of non-divergence for positive tendency centers since Namias (6), Dines (3) and others have noted a frequent tendency for the surface pressure variations to be largely accounted for by the pressure variations above 4 kms.

It thus appears that future investigations should use levels consistently above and consistently below the level of non-divergence and these levels should be selected each day according to the calculated height of the non-divergence level. More will have to be known about the latter problem before much improvement in steering techniques can be accomplished.

The author regrets that due to time limitations many more cases were not tested.

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