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DEPARTMENT OF TRANSPORT

METEOROLOGICAL BRANCH

ANALYSIS OF SOME WINTER NWP FLOW PATTERNS NEAR B.C.

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ABSTRACT

Data extracted from the numerical 500-mb 36-hour prognostic charts prepared by the U. S. Weather Bureau National Meteorological Centre (NMC) for December, 1962, and for January and February of 1963, verified over a twelve-point grid; the errors in the barotropic and baroclinic prognoses were compared, and the general error pattern discussed.

Since the actual vorticity field at 500 mbs was available at 12-hourly intervals on the same series of charts, an attempt was made to relate the occurrence of precipitation at Vancouver, Prince George and Port Hardy to values of the actual vorticity and its 12-hourly change. These vorticity parameters then combined with others representing absolute moisture content and relative humidity to devise a scheme for the objective prediction of rainfall amounts in Vancouver.

This study was undertaken while the author, an undergraduate student at the University of British Columbia, was employed as a student assistant by the Meteorological Branch during the summer of 1963.

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ANALYSIS OF SOME WINTER NWP FLOW PATTERNS NEAR BRITISH COLUMBIA

by

D. D. McLeod

1. INTRODUCTION

It is well known that the simple barotropic numerical weather prediction model does produce at times consistently better results than more complex baroclinic models. The first section of this paper is an objective attempt to determine where, around British Columbia, during the winter of 1962-63, the error patterns of the two models are significantly different, and to determine if this difference in behaviour bears any relationship to areas of significant cyclonic development during these months.

The 36-hour 500-mb height and vorticity forecasts were verified over a grid, consisting of Fort Nelson, Prince George and Port Hardy in British Columbia, ships 4YP, PS23, and PS21 on the Pacific, and another six inland stations: Yakutat, Edmonton, Annette Island, Spokane, Tatoosh Island and Salem. Individual errors in the prognostic values of both 500-mb height and vorticity were derived for each grid point and from them the root-mean-square error was calculated. Error patterns were then constructed for both height and vorticity fields (Figs. 3-6) and will be discussed below.

In addition, the initial vorticity and vorticity change over 12-hour periods were graphed against occurrence and non-occurrence of precipitation at Vancouver, Prince George and Port Hardy. This part of the project was modelled on work done by P. Williams Jr. at Salt Lake City (see bibliography).

Finally an attempt was made to relate 12-hour rainfall amounts at Vancouver to the following four parameters: initial vorticity, 12-hour vorticity change, amount of precipitable water and a measure of the saturation deficit within the air column. It was felt that the first and last of these together would constitute a reasonable measurement of the initial state of the atmosphere, that the second would be an approximate indication of the extent and sign of vertical motion during the 12-hour period and that the third would be directly related to the maximum rainfall possible under ideal rain producing circumstances.

2. STATISTICS

Root-mean square errors for barotropic and baroclinic height and vorticity were calculated using the formula:

$$E = \left[n^{-1} \sum_{2=1}^{n} e_i^2 \right]^{\frac{1}{2}}$$

where E is the rms error, e is the difference between the observed and predicted values; the value of n in this investigation was 100. The values obtained for E are tabulated below, with the stations numbered as follows:

1. Fort Nelson
2. Yakutat
3. Edmonton
4. Prince George
5. Annette Island
6. Spokane
7. Tatoosh Island
8. Port Hardy
6. Picket Ship 21
10. 4YP
11. Salem
12. Picket Ship 23

TABLE 1

RMS Vorticity Error (10^{-5} sec^{-1}) and Height Error (10^{2} ft.)

Station	1	2	3	4	5	6	7	8	9	10	11	12
E barotropic vorticity	2.1	2.5	1.9	2.7	2.7	2.0	2.4	2.5	3.1	3.6	2.2	3.2
E baroclinic vorticity	2.4	2.3	2.2	2.5	2.7	2.5	2.5	2.7	3.3	3.3	2.3	3.3
E barotropic height	1.7	2.5	1.4	2.1	2.3	1.5	1.8	2.1	2.5	2.7	1.4	2.7
E baroclinic height	1.8	2.2	1.7	2.0	2.1	1.8	1.9	2.0	2.6	2.8	1.8	2.9

From this table it was apparent that the values of root-mean square error produced by the barotropic and baroclinic models did not differ greatly at any given grid point. To obtain an estimate of the significance of these differences the standard deviation of the distribution of e^2 was calculated at each grid point for both models. These values (σ) were derived using the formula

$$\sigma = \left[n^{-1} \sum_{2=1}^{n} (E^2 - e^2_2) \right]^{\frac{1}{2}}$$

and are shown in Table 2.

TABLE 2

Mean-Square Vorticity Error (10^{-12} sec^{-2}), Height Error (10^2 ft) and Corresponding Standard Deviations

		BtV	BcV	BtH	BcH		BtV	BcV	BtH	BcH		BtV	BcV	BtH	BcH
E^2	1	447	595	285	324	2	626	528	601	471	3	359	474	190	284
σ		681	1200	482	479		898	907	820	651		558	655	379	452
E^2	4	740	639	453	414	5	707	704	542	454	6	386	605	211	322
σ		1841	1266	748	627		889	1016	827	672		561	859	319	475
E^2	7	588	606	337	360	8	645	713	421	417	9	992	1079	631	664
σ		848	801	508	424		1298	877	734	566		1364	1791	864	950
E^2	10	1287	1104	719	777	11	478	542	198	334	12	1015	1105	749	847
σ		1905	1582	850	978		680	745	305	490		1417	1802	1171	1504

Making the reasonable assumption that the distribution of errors at each point is normal, confidence limits can be calculated for each value of E^2 from the formula:

$$\text{Limiting values} = E^2 \pm Z_c \, \sigma \, (n)^{-\frac{1}{2}}$$

where Z_c is the confidence coefficient. In this analysis $Z_c = 2.58$ for limits in which there is 99% confidence, and these limits for E^2 at each station are given in figures 1 and 2.

The limiting values of the difference between two mean square errors, assuming that each error distribution is normal are given by the formula

$$\text{Difference} = E_1^{\,2} - E_2^{\,2} \pm Z_c \, (\sigma_1^{\,2} + \sigma_2^{\,2})^{\frac{1}{2}} \, (n)^{-\frac{1}{2}}$$

Study of these differences between the mean-square errors in height and vorticity associated with the two models at a given point showed that during this period the models were almost equally effective. However, the differences between the mean square errors at some pairs of points for a single model proved to be significant and the general patterns of error shown in Figures 3-6 are therefore real.

3. PATTERNS OF ROOT-MEAN-SQUARE ERROR

Figures 3 - 6 respectively show the error distribution in the forecast barotropic vorticity, baroclinic vorticity, barotropic height and baroclinic height, during this particular winter.

In all cases the error is significantly greater along longitude 140°W than it is along longitude 115°W. There are most likely several reasons for this characteristic pattern.

(a) The paucity of ocean stations makes the initial analysis rather sketchy and inaccurate in the offshore region. Since the initial input is to some degree in error, the final result compounds this. Precise analysis becomes a possibility east of the coastline, and this precision is reflected no doubt in the area of minimum error over eastern British Columbia.

(b) The long-wave situation during January and February showed a ridge over the British Columbia coast with a trough west of ship 4YP. Most of the cases analysed occurred during these months. Thus cyclonic development was much more likely to occur some distance offshore. This most certainly should result in significant error in barotropic predictions since "development" is not taken into account. However, the error in the baroclinic predictions followed the same pattern and was almost as definite. This indicates an inability of the baroclinic model to predict development of the correct amount and sign, at any rate during the short period considered.

(c) The standard deviation of the 500-mb height (assumed to be the level of non-divergent barotropic flow) is relatively large at all seasons in the north central Pacific and reaches a maximum during the winter months.

4. DEVELOPMENT

On the monthly mean charts prepared by the U. S. Weather Bureau for January and February, it was found that the mean upper flow at Annette, Port Hardy, Tatoosh Island and Salem changed from anticyclonic in January to cyclonic in February. Since development occurs most frequently only in regions of cyclonic upper flow, and since the largest errors in the numerical models are often due to their inability to predict development, it was felt that the rms errors would be larger in February. This is borne out on the average but the results, shown in Table 3, do not show a very coherent pattern.

TABLE 3

RMS Errors (10^{-5} sec^{-1}, 10^{2} ft) for January and February at Coastal Stations (28 cases each month)

Station		5	7	8	11
E' BtV	January	2.2	2.5	2.5	1.9
	February	2.5	2.1	2.4	2.4
E' BcV	January	2.4	1.7	2.9	2.0
	February	3.0	2.1	2.5	1.9
E' BtH	January	1.9	1.9	1.7	1.5
	February	2.7	1.8	2.3	1.4
E' BcH	January	2.3	1.5	1.7	1.5
	February	2.2	1.7	2.0	1.7

Read with the sampling distribution error in mind, though, the results are not quite as random as they appear. This error, estimated at about 20-25% of the rms values, was not calculated because a minimum of 30 cases is needed to find the standard deviation. Unfortunately, only 28 of a possible 62 charts for January, were either received or readable.

It was also hoped that a further investigation of these data could be undertaken, to compare the differences between the barotropic and baroclinic errors for January, with the February differences, and thus verify the theory that the baroclinic model is better than the barotropic in predicting development. Because of uncertainty in the data, this was found to be impracticable.

5. QUALITATIVE PRECIPITATION FORECASTS

The occurrence and intensity of rainfall are related, among other things, to the vertical motion of the atmosphere. An attempt was therefore made to relate rainfall occurrence in any 12-hour period to the change of vorticity at the 500-mb level during the period and to the vorticity existent at 500 mbs at the beginning of the period. Vorticity values were readily available on the NMC Observed Vorticity Charts, and 12-hour changes were easy to compute. Records of rainfall occurrence and amount were available at Vancouver International Airport for each 6-hour interval at major stations in British Columbia.

This study of course involves the use of an analysed field at the end of the period over which the rainfall is measured and therefore might be considered of slight operational value compared with, say, a technique involving measurement of vorticity advection over the area at the beginning of the period. However, this latter comparison was rejected for the following reasons:

(a) the physical difficulty of making an accurate assessment of vorticity advection on facsimile charts of the scale and quality available

(b) the availability of predicted vorticity fields on an operational basis. Numerical Weather Prediction systems presently provide useable fields of predicted vorticity for periods up to 30-hours ahead of data time. Forecasters are already considering these predicted changes, among other things, during their assessment of weather producing synoptic scale systems. This study relating rainfall to actual changes in vorticity therefore implies the availability of perfect prognostics and should permit the placing of an upper limit on the usefulness of the parameter as a predictor of rainfall.

In figures 7, 8 and 9 are shown the results of graphing precipitation occurrence against initial vorticity and 12-hour vorticity change at Vancouver Airport, Port Hardy and Prince George during the period of study. Each graph is divided into four areas by three curves. All points in area A are expected to have a rainfall probability of less than 10%, those in area B about 50%, in area C about 70% and in area D about 90%. The quasi-parabolic nature of the curves was thought to be real but this relationship requires additional justification since the number of cases was not enough to be certain.

In figure 9 (the graph for Prince George) the axis of the system of curves lies along the line representing an initial vorticity of 12×10^{-5} sec^{-1}. This is possibly due to the fact that the main flow subsides as it moves over the Cascades down into the interior plateau at Prince George, thus creating a negative component of vorticity which has to be overcome before substantial rainfall can occur. This would have the effect of raising the 'threshold' value for each probability of rainfall occurrence and consequently would shift the system of the curves to the right. At Vancouver and Port Hardy, the orographic lift of the mountains to the east is likely to give an opposite effect, and the axis value of 10×10^{-5} sec^{-1} confirms this. It will be noted that the minimum ordinate of the system of curves occurs at lower values of 12-hour vorticity change at Port Hardy than at Vancouver or Prince George. It was felt that this could be due to an uneven distribution of 'rain' and 'no rain' cases. The distributions are given in Table 4 below.

TABLE 4

	Vancouver	Port Hardy	Prince George
Rain	83	104	82
No rain	76	52	74
Total cases	159	156	156

6. QUANTITATIVE PRECIPITATION FORECASTS

Since 500-mb vorticity values over Vancouver were available at the beginning and end of each 12-hour period, an attempt was made to combine vorticity parameters with moisture parameters in an attempt to arrive at quantitative estimates of 12-hour precipitation. The actual parameters considered were:

(a) Vorticity at mid period

(b) Vorticity change during period

(c) A measure of the mean relative humidity at mid period in a representative air column

(d) Amount of precipitable water available.

It was felt that the first two variables would be representative of large-scale vertical motion, the third of the initial state of the atmosphere, and the fourth of the moisture available. There are other factors of significance at times, but it was felt that these should account for most of the day-to-day variation in rainfall. The radiosonde ascent at Tatoosh was considered to be representative of moisture conditions over Vancouver since a twelve-hour trajectory would as a rule have a length of two or three hundred miles. In this analysis precipitable water was computed from a standard tephigram plot; the air column was divided into three layers 1000-500 mb, 850-700 mb and 700-500 mb; the mean mixing ratio was computed for each layer visually and the values summed to represent the amount of precipitable water available. The method is described in more detail in reference (2). The saturation deficit was taken to be the sum of the temperature-dewpoint depressions at 850-mb, 700-mb and 500-mb levels. The vorticity data were used with only one change from the method of the previous section. In place of the initial vorticity, ζ, at 0000Z and 1200Z an average was used such that

$$\zeta_{AV} = \zeta_o + \tfrac{1}{2}\Delta\zeta$$

This was done because the values of precipitable water and saturation deficit used were averages of observations representative of the beginning and end of the twelve hour period. The two initial graphs are shown in Figures 10 and 11. Rainfall amounts are plotted for each pair of parameters. Reasonably smooth isopleths were drawn on both diagrams, and numbered in proportion to the rainfall amount. Both graphs are combined in Figure 12. It will be noticed that while all parameters do effect some separation in the rainfall amounts, other factors also are at work. The final diagram (Figure 12) is most effective in a negative sense. On it, low values of the derived parameters are indicative of slight or no precipitation. The isopleths are drawn without bias or distortion to suit this particular run of data. Nevertheless 93% of the points in area "A" report precipitation of one-tenth of an inch or less and 92% of all points in areas "A" and "B" together report precipitation of two-tenths or less. The heavier rainfalls do not conform nearly so readily.

7. CONCLUSIONS

During the period of this study, there was little to choose between the barotropic and baroclinic models in use at the time. The flow patterns predicted by both models showed error patterns very similar in form and intensity over the eastern Pacific and British Columbia. However, the investigation was limited by the amount of data available and the time required to process it by hand. With a longer run of data it should be possible to establish with precision whether one model is definitely superior on the average, and more importantly, the synoptic conditions under which this superiority is most often or most clearly demonstrated.

The relationship between vorticity parameters and the occurrence or non-occurrence of precipitation was of a character justifiable on physical grounds, but it is doubtful if it was strong enough to be of forecasting use. Here again a longer run of data would have increased confidence in the probabilities computed. The inclusion of moisture parameters in an attempt to derive rainfall amounts enjoyed about the same degree of success. The relationship of rainfall amount to the parameters considered was again of a general character justifiable on physical grounds. However, a significant percentage of cases departed from the general pattern, which itself could not be clearly established due to the limited number of cases considered. This showed that either

(a) other parameters of significance had been neglected, or

(b) that the parameters used were not measured with a sufficient degree of accuracy or

(c) that a spot value of rainfall is not truly representative of that occurring over an area suited to the spatial scale of this investigation.

It was thought that all three factors contributed to the indefiniteness of the results.

In an area such as British Columbia it is almost essential that parameters such as stability and orography be taken into account and that areal rather than point precipitation be considered.

APPROVED,

J. R. H. Noble,
Acting Director.

8. BIBLIOGRAPHY

(1) Relationship of Precipitation to Vorticity and Vertical Motion at Salt Lake City. Monthly Weather Review, Volume 91, Number 5, pp 215-219.

(2) A Tephigram Overlay for Computing Precipitable Water. Technical Circular 409, Canada, Department of Transport, Meteorological Branch, May, 1962.

FIG. 1- 99% CONFIDENCE VALUES OF ROOT-MEAN SQUARE BAROTROPIC AND BAROCLINIC HEIGHT ERROR

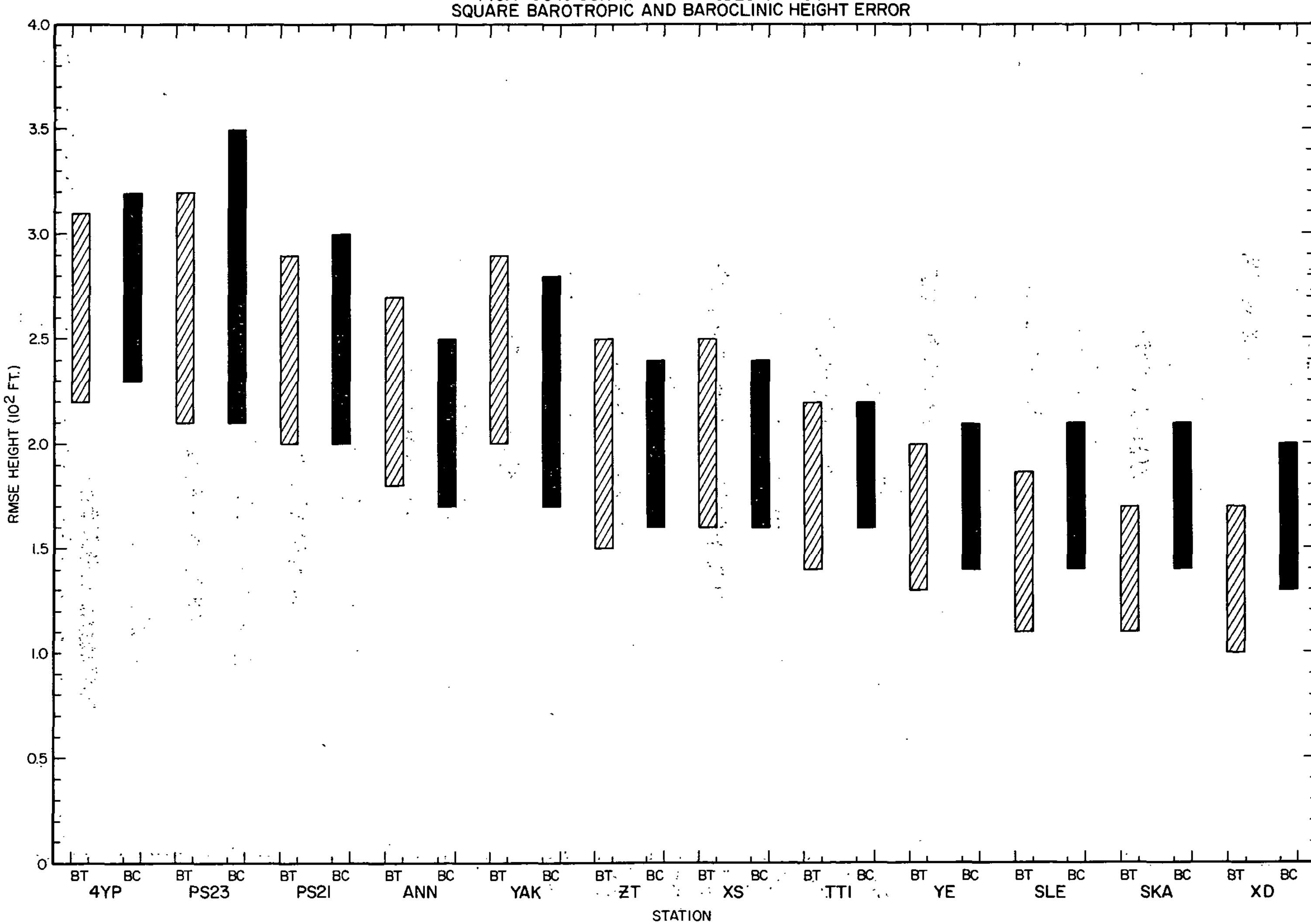

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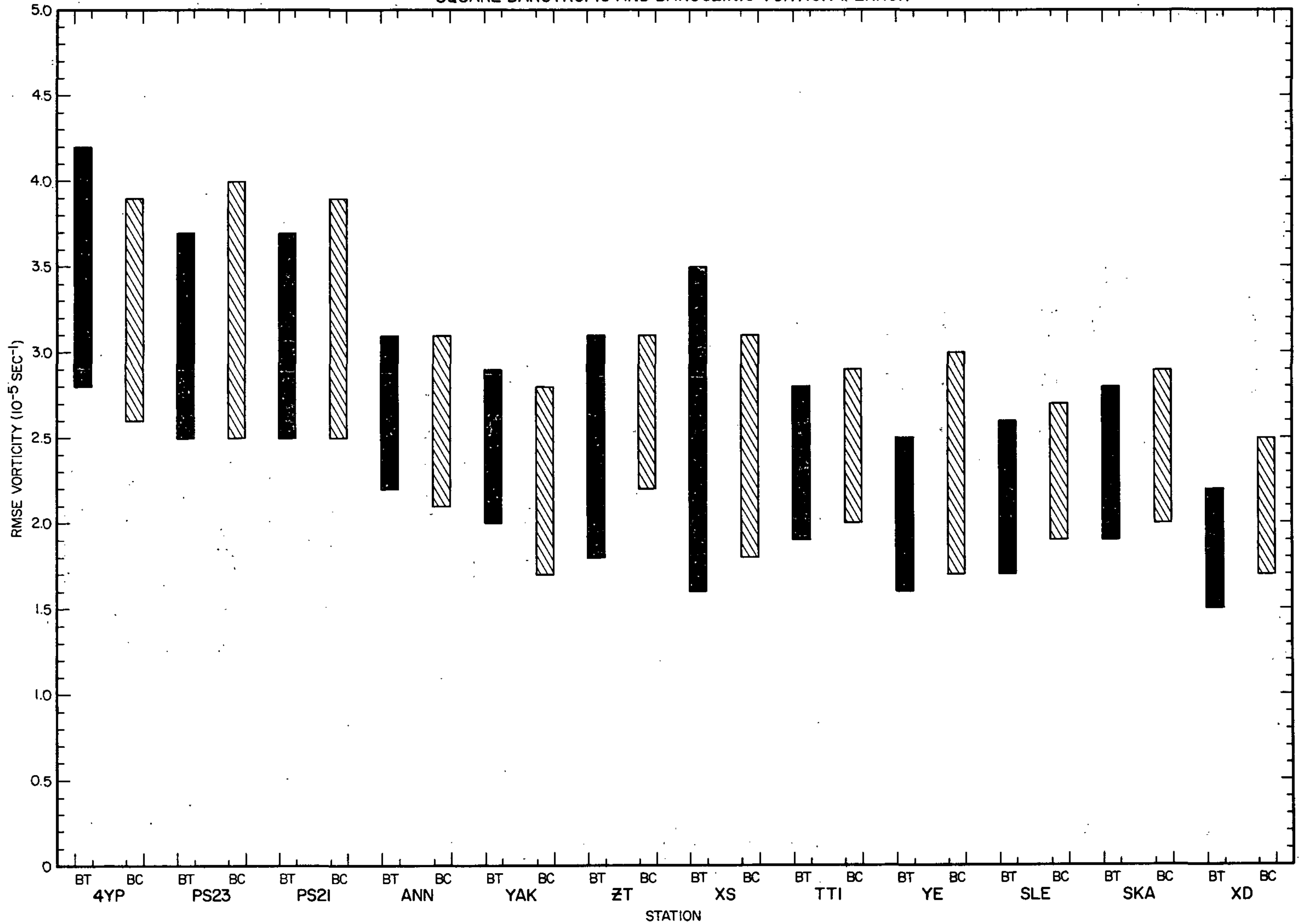
FIG. 2-99% CONFIDENCE VALUES OF ROOT-MEAN SQUARE BAROTROPIC AND BAROCLINIC VORTICITY ERROR



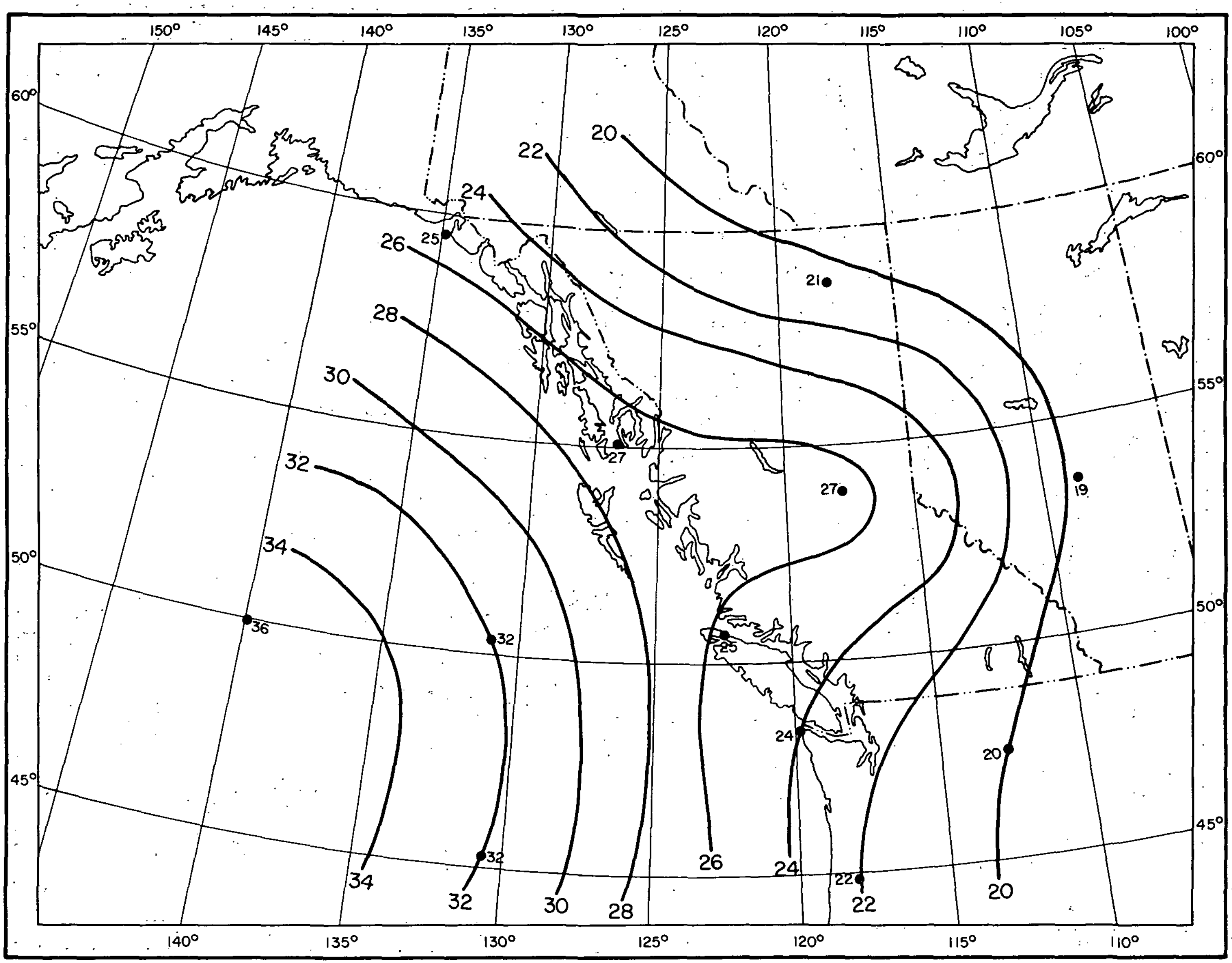


FIG. 3

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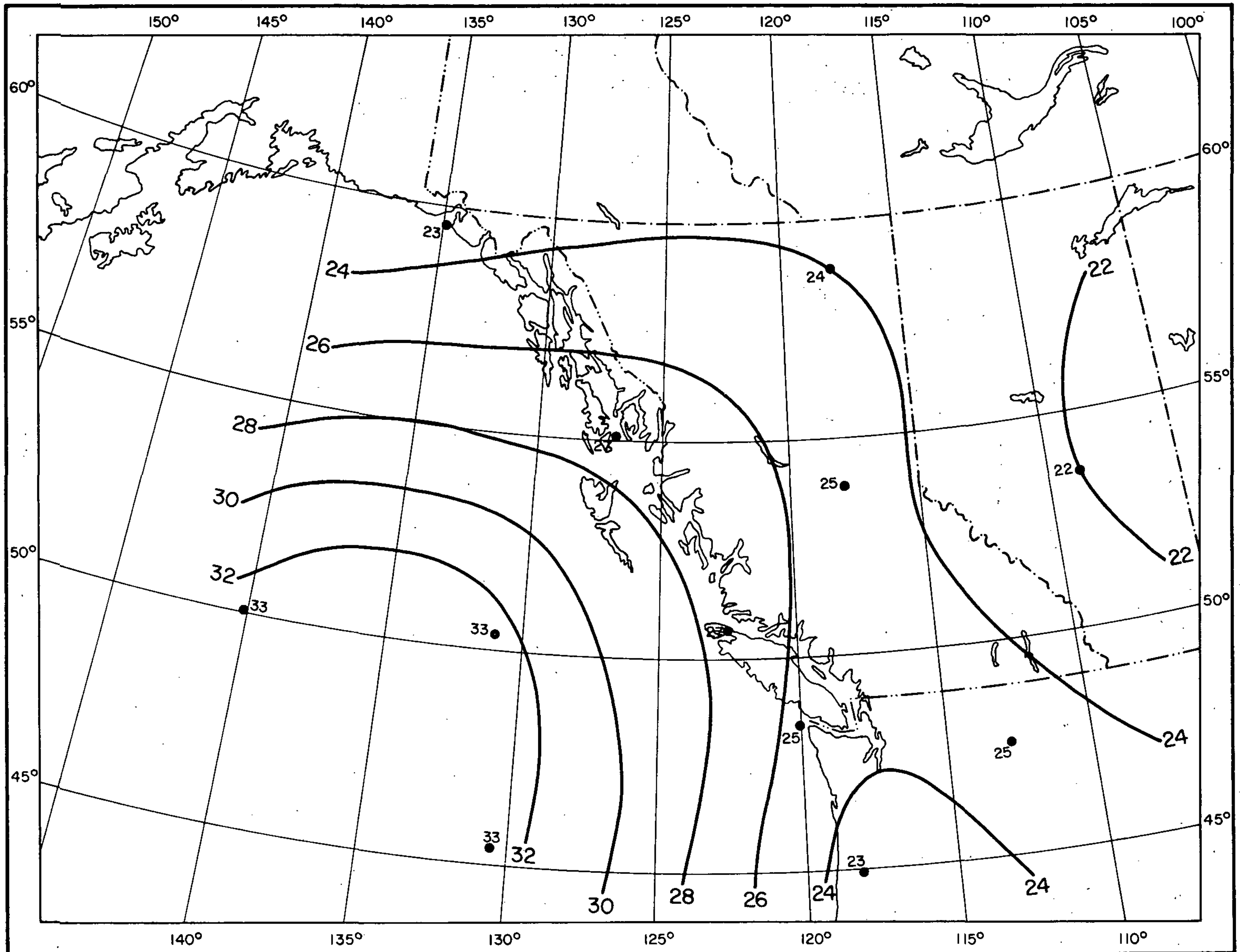

FIG. 4

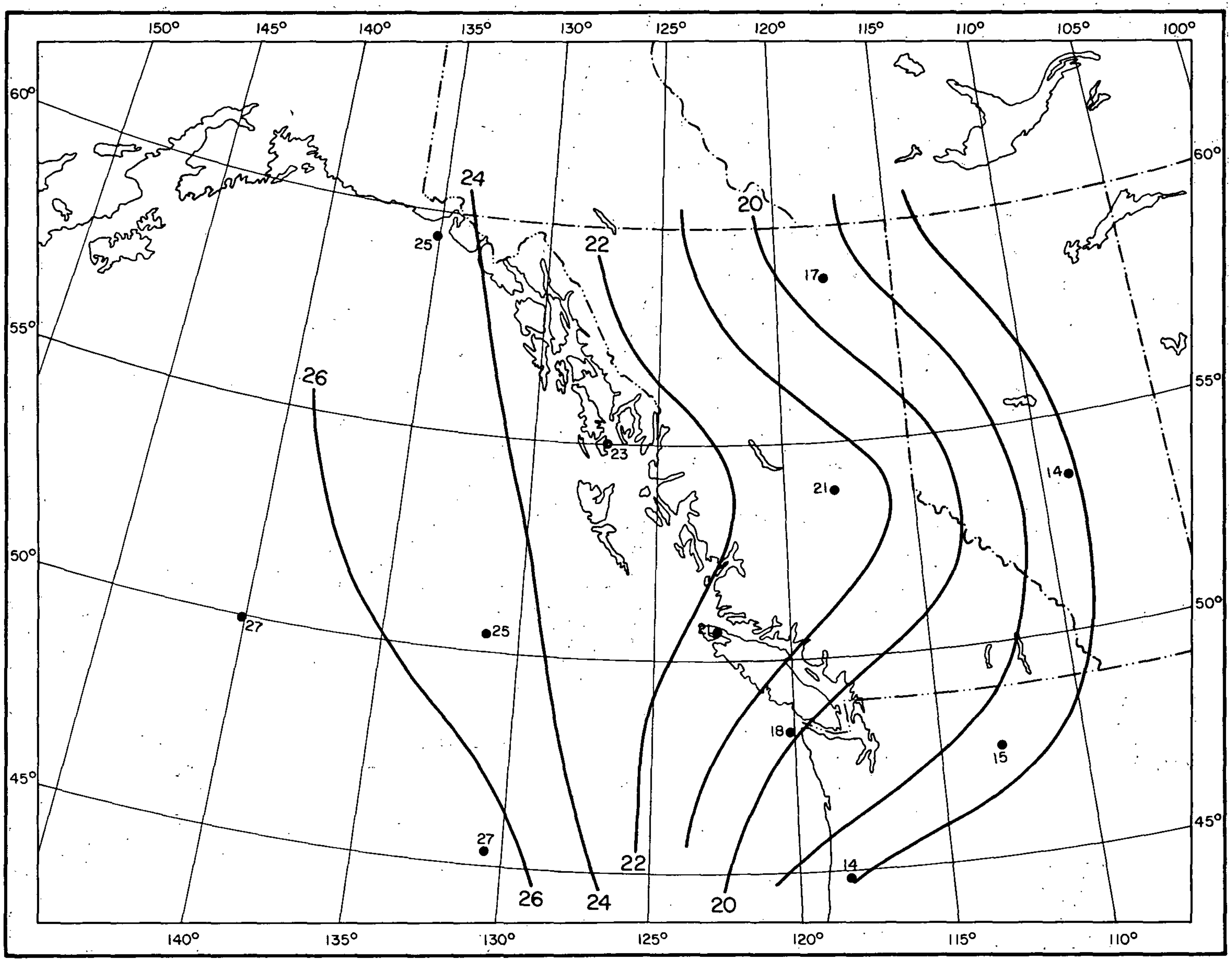

FIG. 5

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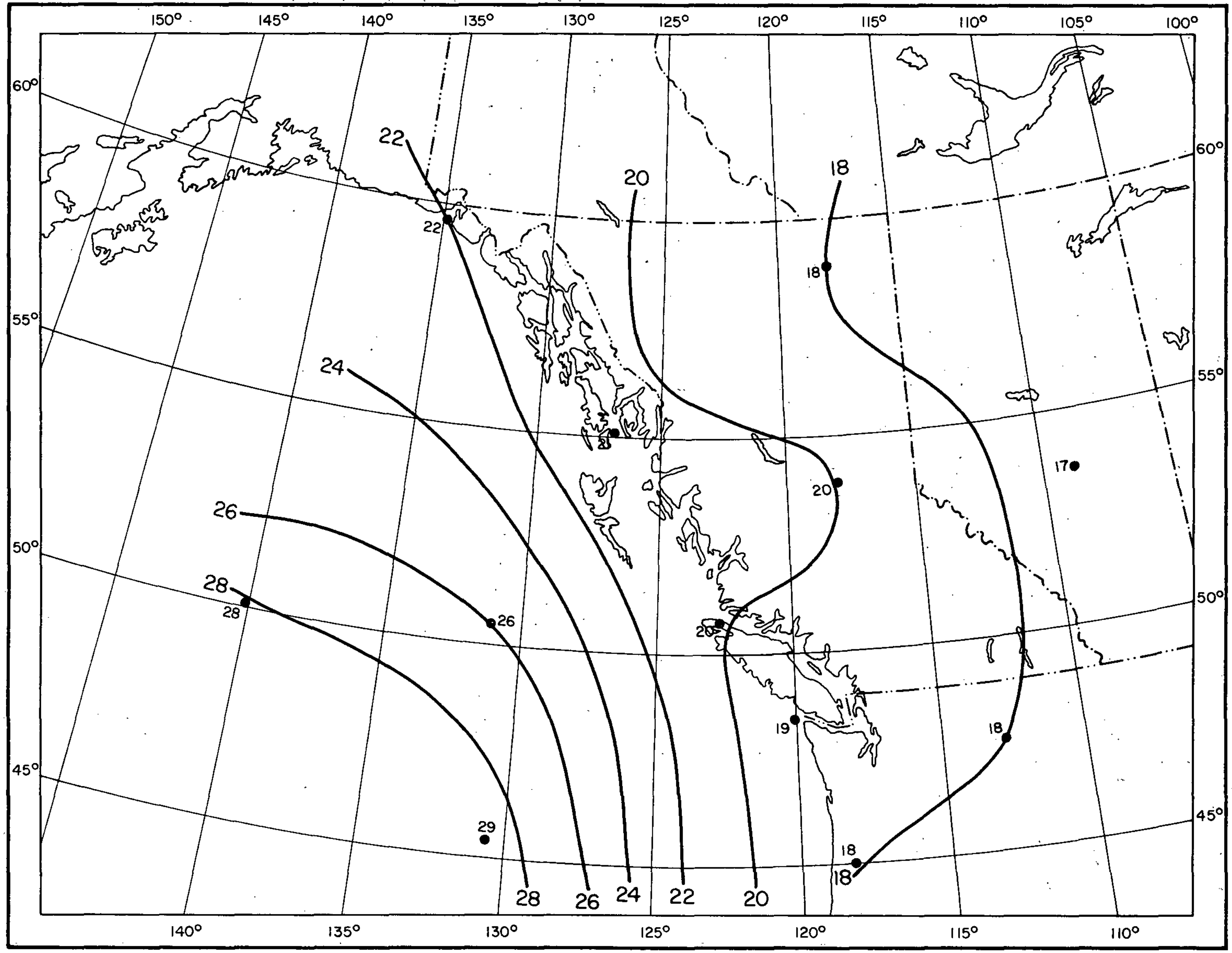

FIG. 6

FIG. 7-OCCURRENCE OF RAIN AT VANCOUVER, B.C.

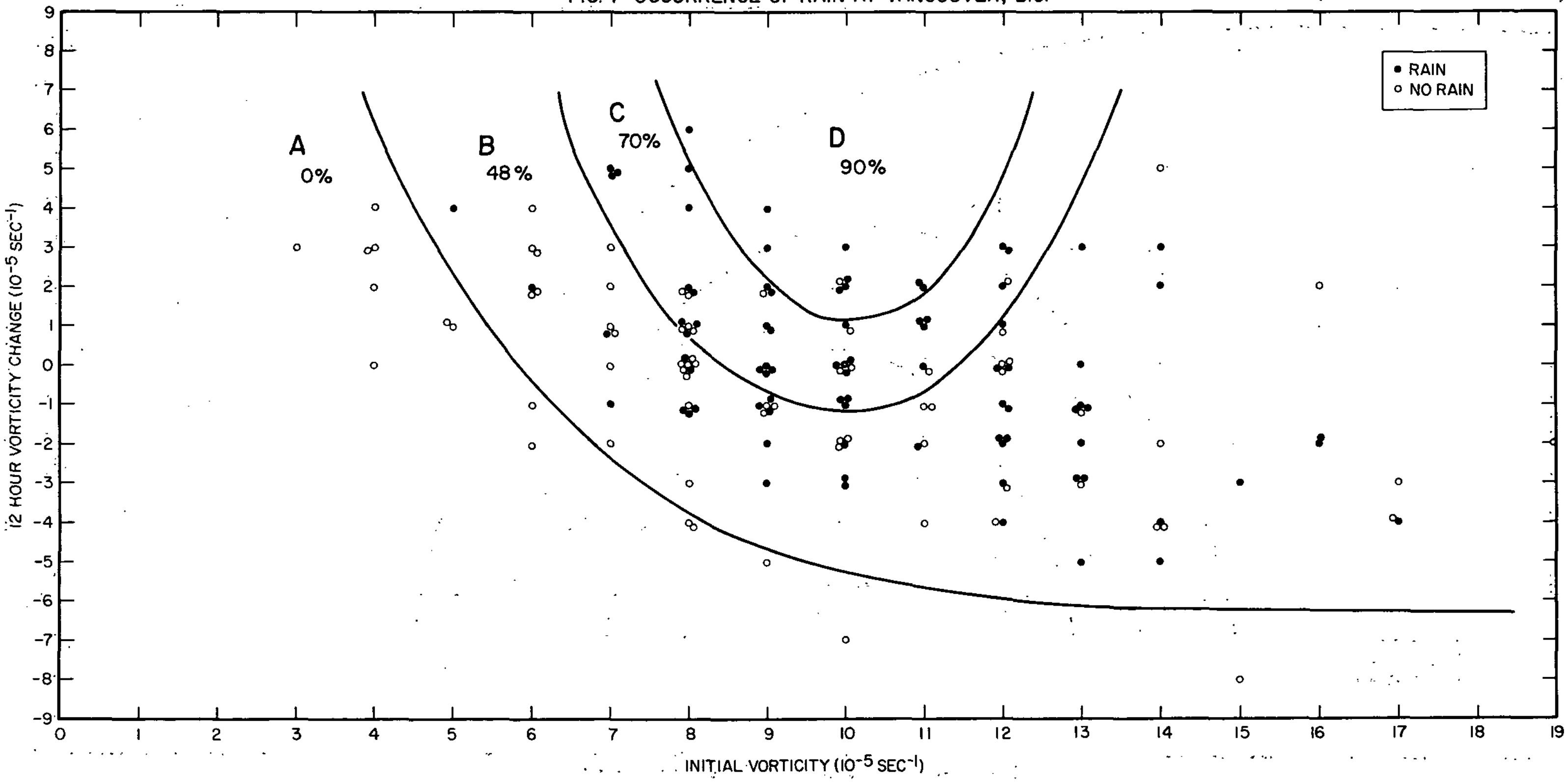

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FIG. 8-OCCURRENCE OF RAIN AT PORT HARDY, B.C.

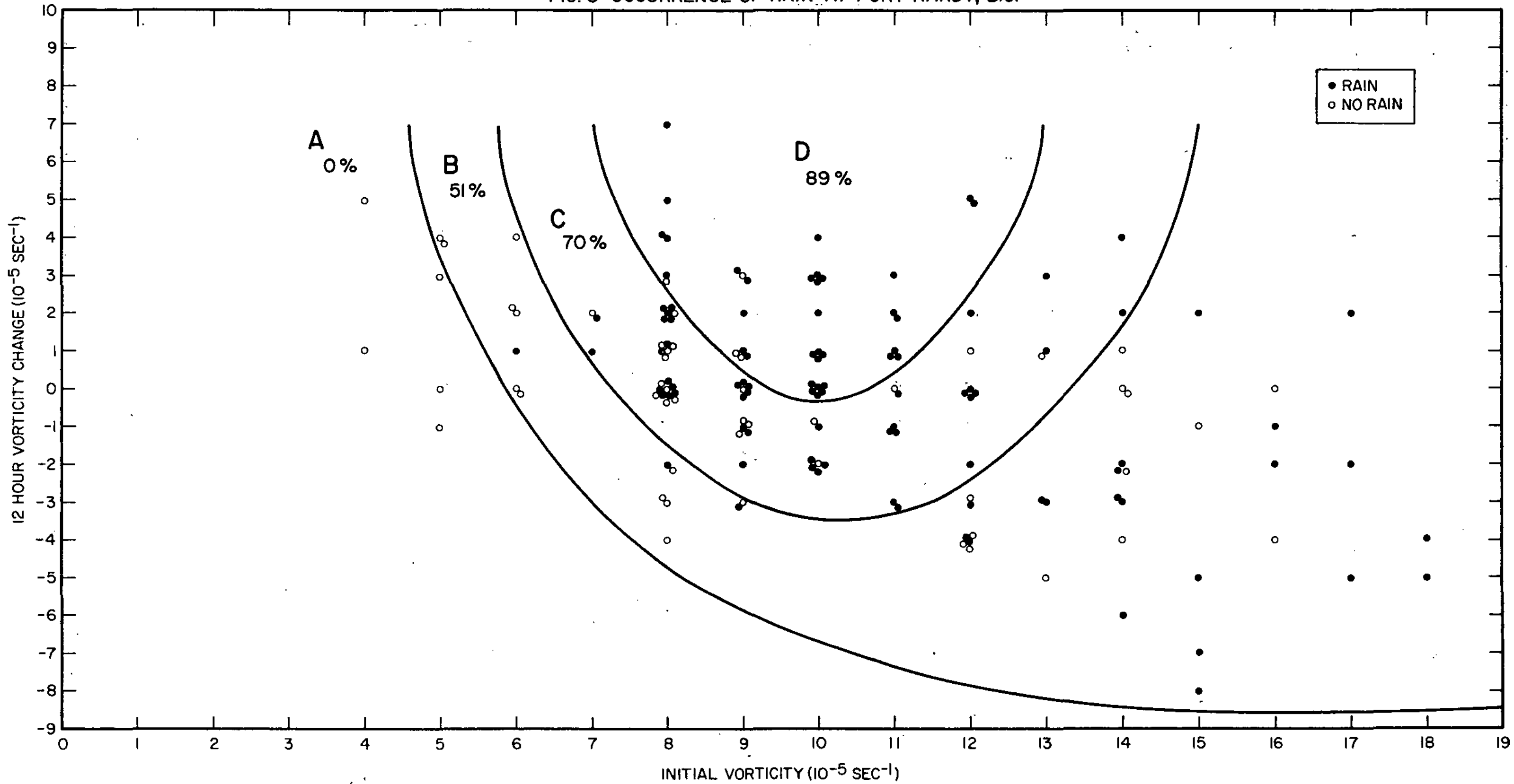

FIG. 9- OCCURRENCE OF RAIN AT PRINCE GEORGE, B.C.

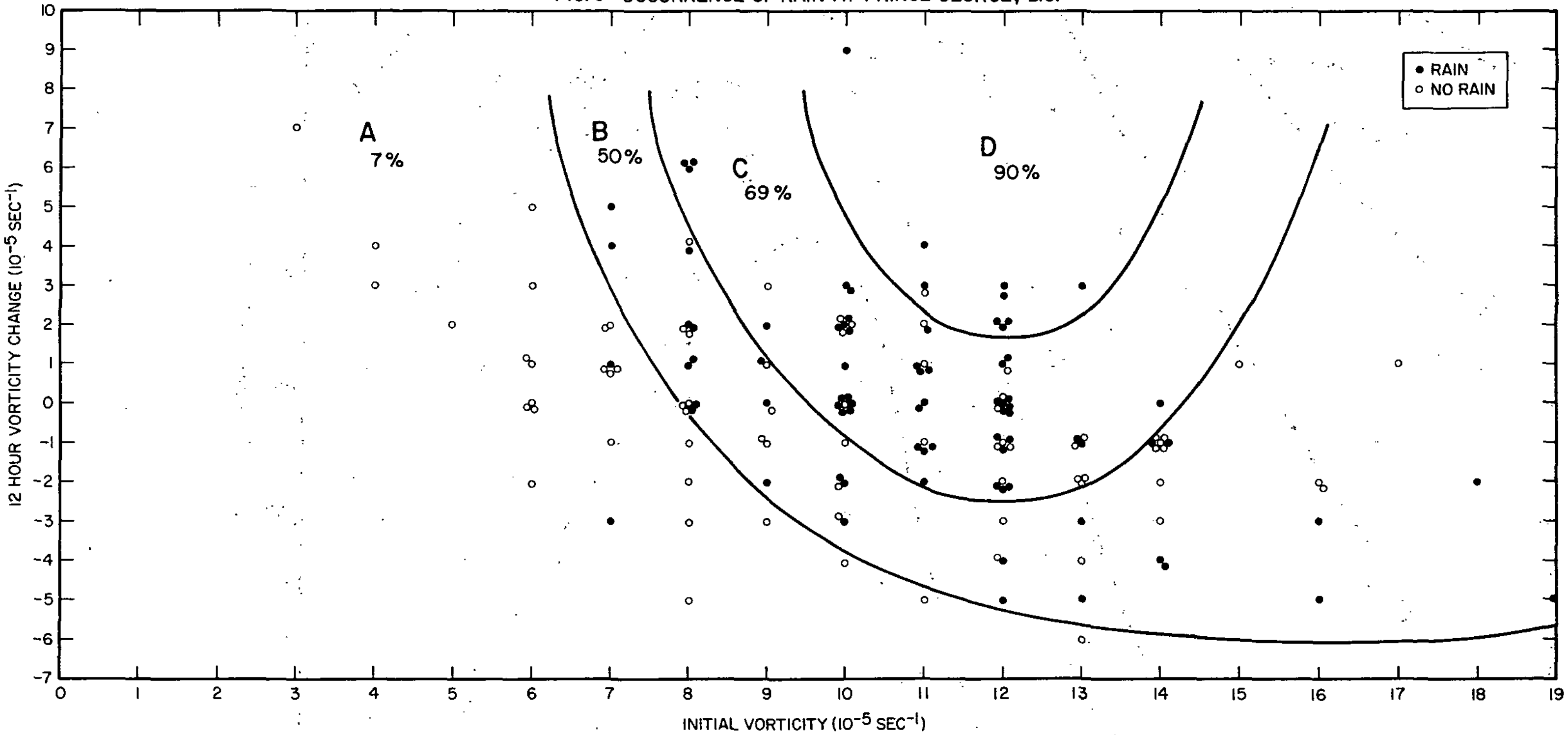

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FIG. 10 - RAINFALL AMOUNTS AT VANCOUVER, B.C.

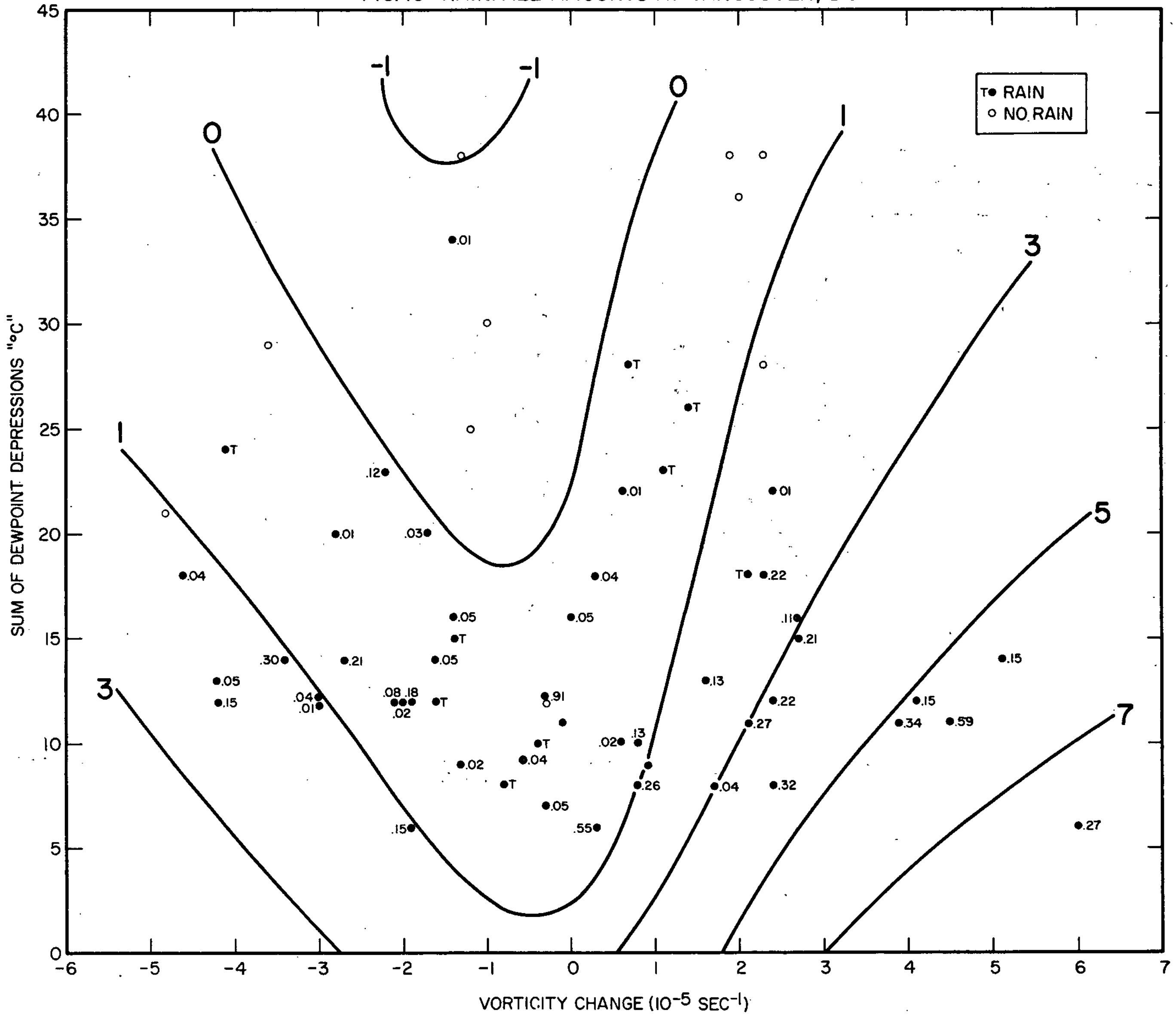

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FIG. 11 - RAINFALL AMOUNTS AT VANCOUVER, B.C.

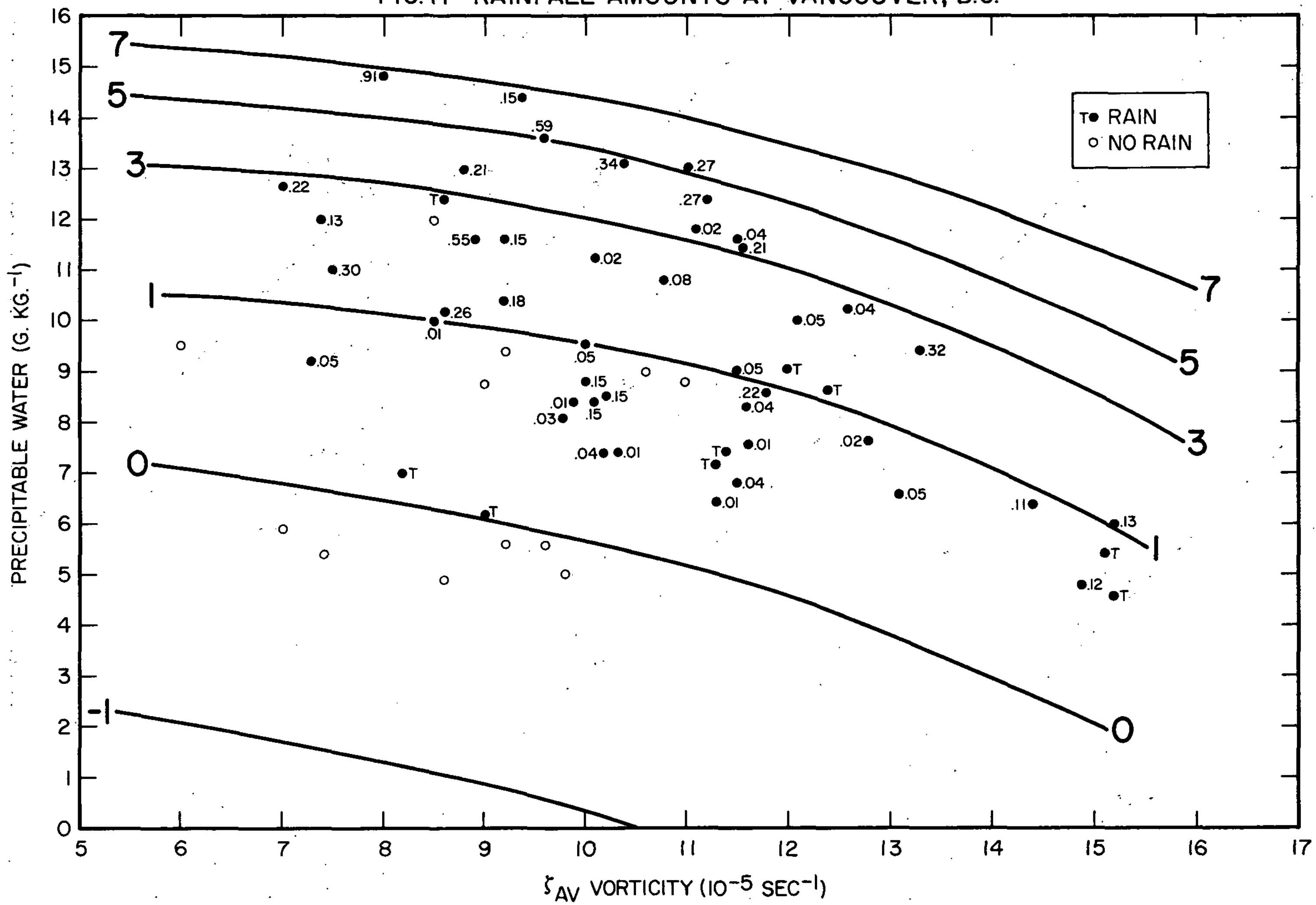

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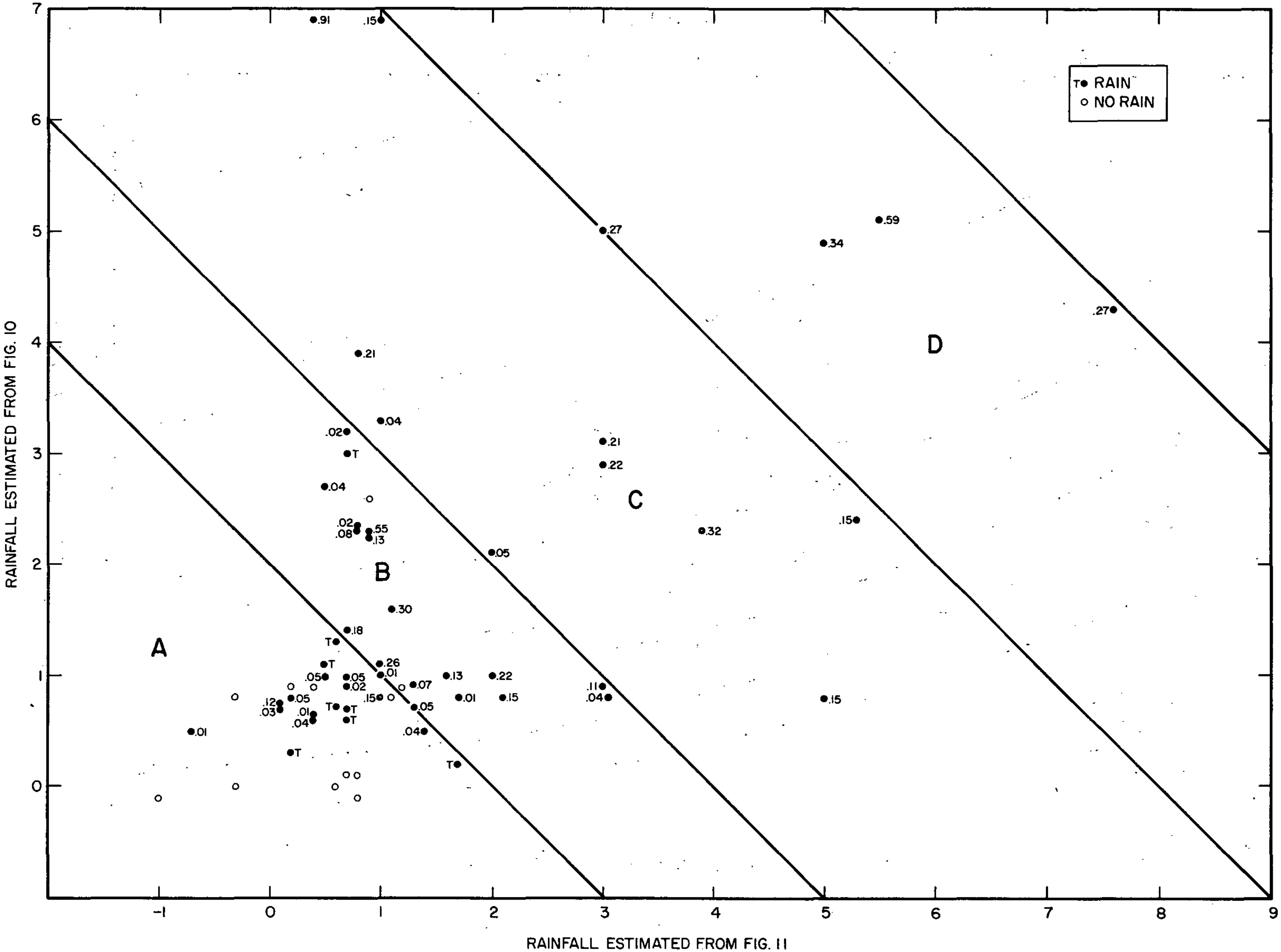
FIG. 12- RAINFALL AMOUNTS AT VANCOUVER B.C.



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