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Synoptic Climatological Studies of Precipitation in the Plateau States From 850-Millibar Lows During Fall

AUGUST F. KORTE AND DEVER COLSON

Systems
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SYNOPTIC CLIMATOLOGICAL STUDIES OF PRECIPITATION IN THE PLATEAU STATES FROM 850-MILLIBAR LOWS DURING FALL

August F. Korte and DeVer Colson

Systems Development Office
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551.5	Meteorology
.515	Atmospheric disturbances
.127	Distribution of elements in upper air
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.36	Frequency of precipitation
.589	Synoptic climatology
.1	Frequency of elements associated with synoptic types
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SYNOPTIC CLIMATOLOGICAL STUDIES OF PRECIPITATION IN THE PLATEAU STATES FROM 850-MILLIBAR LOWS DURING FALL

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ABSTRACT. Presented is a synoptic climatology of precipitation from upper level Lows at 850 mb over the Plateau States or intermountain region of the western part of the United States during September, October, and November. The upper Lows were classified into three intensity categories based on the departure from the mean of the central height. The average precipitation amount, distribution, and frequency of occurrence are derived and related to the level, intensity, and location of the upper Low. The geographical distribution of the 850-mb Lows is shown. Precipitation amounts at 157 stations for 12-hr periods (centered at upper air observation times and expressed as percentages of 7-day station amounts) are related to the position of the Low centers by means of a moving grid system. Average amounts and probabilities of occurrence at 35 selected stations are calculated using a fixed grid. From the moving (storm-centered) grid, we found that many precipitation probability maxima are located more to the northeast than those in earlier studies. The fixed (station-centered) grid results show considerable variation in precipitation probabilities among the 35 stations. Generally, the precipitation specification is least with weak (class I) Lows and greatest with the strongest (class III) Lows.

1. INTRODUCTION

A synoptic climatology has been prepared relating precipitation in the Plateau States or intermountain region of the western part of the United States to upper cyclones during winter and spring (Jorgensen et al. 1966, 1967a, 1967b; Klein et al. 1968; Korte et al. 1969; and Korte and Colson 1972). In the present study, we extend this investigation into fall (September, October, and November) and compare results with those for winter and spring.

The atmospheric circulation is responsible for supplying the moisture required for precipitation. Over the Plateau States or Intermountain West, precipitation results from two main factors: (1) dynamic mechanisms within the low-pressure area and (2) orographic lifting. Mountain ranges that lie across moisture-laden air flow receive the larger percentage of precipitation on the windward side while a rain shadow exists on the leeward side.

Characteristics of the atmospheric circulation can be related to the associated weather (including precipitation) to give a synoptic climatology. In this sense, a synoptic climatology may be defined in terms of synoptic weather information (Huschke 1959). Once such a synoptic climatology has been developed, it can be used as a forecasting aid, given an accurate prognostic chart of the Low center.

In an earlier paper, Klein et al. (1968) showed that 850-mb Lows are closely related to winter precipitation in the Plateau States. Thus in the present study, we limited the investigation to the 850-mb level. Already known is the fact that low-pressure circulation centers aloft are an important cause of precipitation. These systems can produce upward air currents that may result in nonorographic precipitation, which is then augmented or diminished by orographic factors.

In the present study, precipitation data for 12-hr periods are related to (1) the position of the low-pressure centers when using a moving grid (with precipitation expressed as percentages of 7-day normal amounts) and (2) the position of the Low centers with respect to the location of each of the 35 selected stations (table 3, appendix) when using a fixed grid (with precipitation expressed in actual amounts). Electronic computers were used in developing the required relationships between the synoptic patterns and precipitation.

2. DATA

The period of record (1952 through 1964) used in an earlier paper (Korte et al. 1972) is also used in the present study. Positions and characteristics of the 850-mb Lows were tabulated for September, October, and November. The associated precipitation amounts were obtained from the National Climatic Center (NCC) at Asheville, N.C.; the amounts are summed for 12-hr periods centered at upper air observation times (0300 and 1500 GMT up to June 1, 1957, and 0000 and 1200 GMT for the remainder of the data period). The final results are applicable to 12-hr periods centered at 0000 and 1200 GMT. The upper Low observational area and the precipitation station network are shown in figure 1.

The grid system employed is the same as the one used in the previous studies. Figures 2A and 2B respectively represent the moving grid and the fixed grid. To investigate precipitation relative to cyclonic centers, one places the origin at the Low center and moves the grid with the center. Occurrence or nonoccurrence of precipitation at the recording stations is examined by the computer and allocated to the appropriate grid cell in which the station is located. When more than one report falls within a cell, an average value is considered to be located at the center of the grid cell. The average amounts of precipitation (expressed as a percent of the 7-day normal) are computed in the grid cells. When investigating the precipitation at individual stations, the grid (fig. 2B) is centered on the station and remains stationary. In figure 2B, the actual total recorded precipitation was used with the grid instead of a percentage of the 7-day normal precipitation.

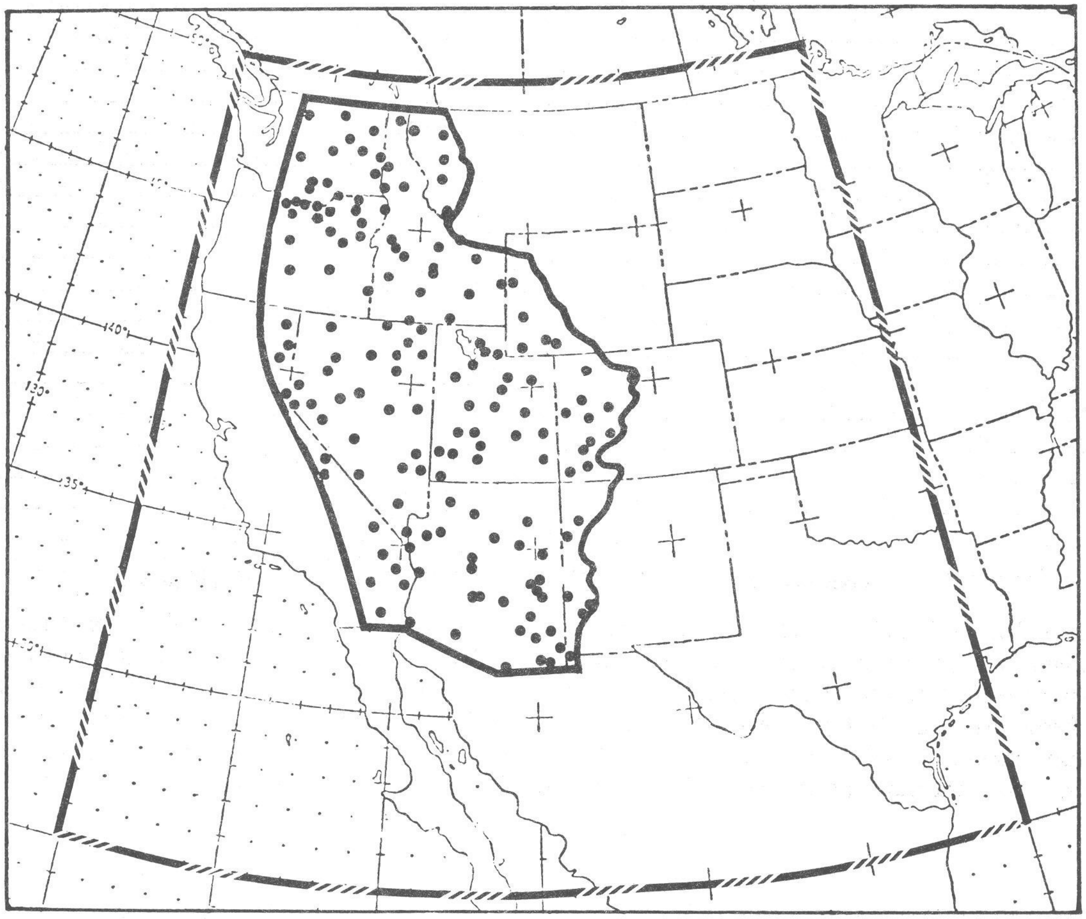

Figure 1.--The observational area (enclosed by the heavy dashed lines) from which the upper Low data were obtained and precipitation network (heavy black dots)

Positions of the 850-mb Lows were read to within 0.5° latitude and longitude. Their intensities were indicated by taking the departure (of their central heights) from normal (DN) values for various periods (Klein et al. 1968; Korte 1971; Korte and Colson 1972 ; and Korte et al. 1972). The Lows were grouped into three classes by dividing the overall range of intensities into three intervals similar to those used in the earlier studies. Class I represents the weak cyclones; class II, those of intermediate intensity; and class III, the most intense Lows. Table 1 gives the class limits and the number of 850-mb Lows for these three classes.

The distribution of Lows for the fall months (fig. 3) shows widely scattered isolated maxima. The highest frequencies occur to the west of the Great Divide in Nevada and northwest Mexico, with secondary maxima east of the divide. In spring (Korte et al. 1972), the maxima are larger and also occur both to the east and west of the divide. In winter (Klein et al. 1968), the distribution shows the highest frequency considerably to the east of the Great Divide (New Mexico, Kansas, and Oklahoma).

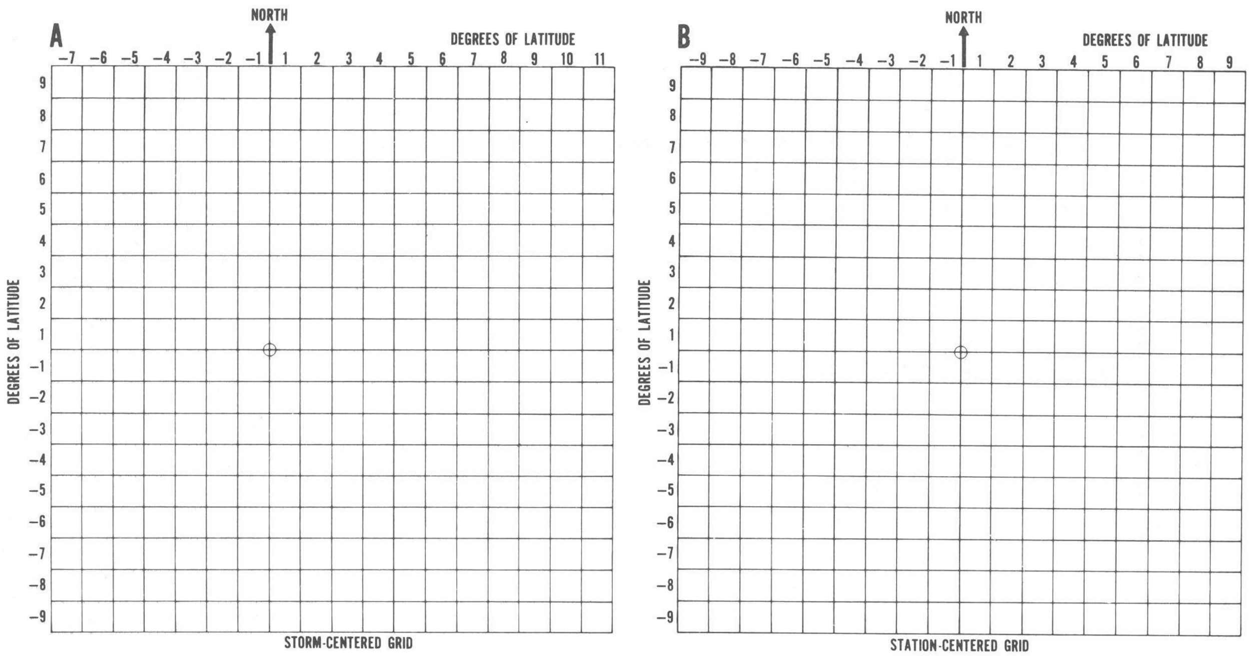

Figure 2. -- Grid representation on a plane surface. The grid system consists of great circles on the spherical earth with dimensional units equivalent to latitude degrees along the two axes. (A) is for the storm-centered (moving) grid with its origin displaced 2° toward the west because greater rain areas can be expected to the east of the upper Low center; and (B) is for the station-centered (fixed) grid with the origin at its center.

Table 1. -- Class intervals of the DN, defining the 850-mb Low categories during fall

	Class I	Class II	Class III	
DN height of Lows (in m)				
	>-30	-30 to -100	<-100	
Number of Lows				Total
	288	581	260	1,129

The total of 1,129 Lows recorded during fall is nearly the same as the 1,110 in winter but considerably less than the 1,613 in spring. The distribution of the 850-mb Lows is shown in table 2 which indicates that the percentage of Lows investigated for the three seasons is smallest during winter and increases toward summer.

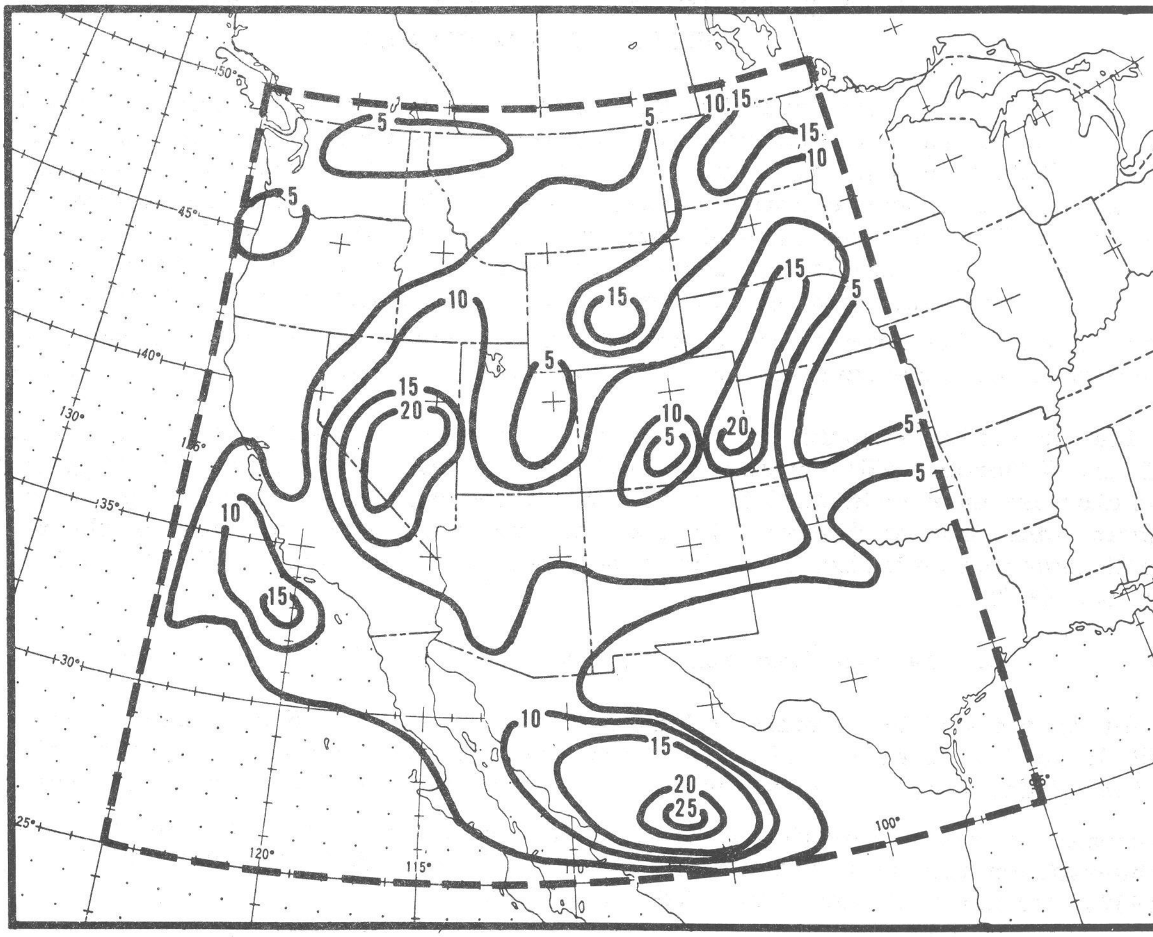

Figure 3. -- Distribution of major Lows of all intensities at the 850-mb level over the observational area during fall (September 1952 through November 1964). The frequencies are analyzed as the total number of occurrences per 2° latitude square.

Table 2. -- Number of 850-mb Lows by seasons and percentage of occurrence by months

Fall	1,129	Winter	1,110	Spring	1,613
Sept.	38 %	Dec.	32 %	Mar.	30 %
Oct.	33 %	Jan.	34 %	Apr.	32 %
Nov.	29 %	Feb.	34 %	May	38 %

3. FREQUENCIES AND AVERAGE AMOUNTS OF PRECIPITATION RELATIVE TO LOW CENTERS

To investigate the frequency of occurrence and average amount of precipitation about the Low centers, we centered the moving grid shown in figure 2A on the Low and allowed it to move with the Low center. Cases falling in each grid cell were examined by computer, as described earlier (Jorgensen et al. 1966), for the three intensity classes at the 850-mb level to determine the relative frequency with which precipitation occurred within the grid area surrounding the Low center. These data were plotted and analyzed in the form of frequency charts. Corresponding average amounts expressed as a percent of the 7-day normal were similarly plotted and analyzed.

The resulting synoptic climatology has been expressed in the form of charts (figs. 4 through 18) showing quantitative values and frequencies of precipitation in each grid cell in relation to the position and DN value of the upper level Low at 850 mb. In the next topic is a comparision of the 850-mb fall Lows with similar Lows for other seasons (Klein et al. 1968 and Korte et al. 1972).

A. Average Precipitation Amounts With 850-Millibar Lows

As in our earlier studies (Jorgensen et al. 1966, 1967a; Klein et al. 1968; and Korte et al. 1972), the analysis of average amounts of precipitation (figs. 4-6) is expressed as percentages of the 7-day station normals assumed at the center of each grid cell for 12-hr periods centered at the observation times of 0000 and 1200 GMT (0300 and 1500 GMT prior to June 1957) for each of the three classes of Lows.

Figure 4 for class I Lows shows maximum average amounts of precipitation east and south of the Low center. These maxima exceed those of winter and spring; but after omitting a few isolated values, most amounts are less than 20 %, which is comparable to the values for spring and winter. In spring, the largest amounts were to the southeast; in winter, the largest amounts were near and to the southwest of the Low center.

The analysis of class II Lows (fig. 5) indicates that the higher average amounts of precipitation occur in a large area ranging from south to northeast of the Low center. An insignificant amount or no precipitation occurred in the cells in the extreme northwest and southeast portions of the grid. In spring, the largest amounts occurred to the southwest and east; in winter, they occurred to the east and south. The amounts in the fall are generally more than those in winter and spring.

For the most intense Lows (class III), the average values are considerably larger (fig. 6). The maxima occur to the northeast of the grid center, with insignificant amounts or no precipitation in the southeast and northwest portions of the grid. The amounts are more nearly comparable with those in spring and winter. However, the largest values were more to the northeast and southeast in spring and to the northeast and southwest in winter.

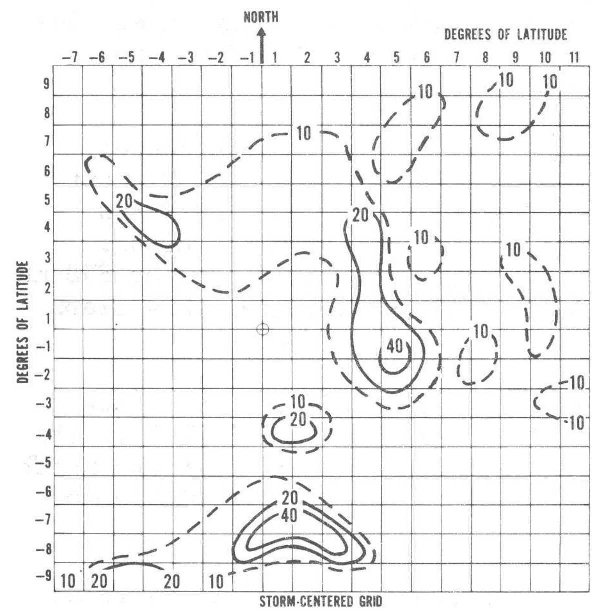

Figure 4. -- Analysis of the average amounts of precipitation for class I Lows. The amounts during the 12-hr period centered at the upper air observation times are expressed as a percentage of 7-day station normals. The upper Low is centered at the origin, with the grid network as given in figure 2.

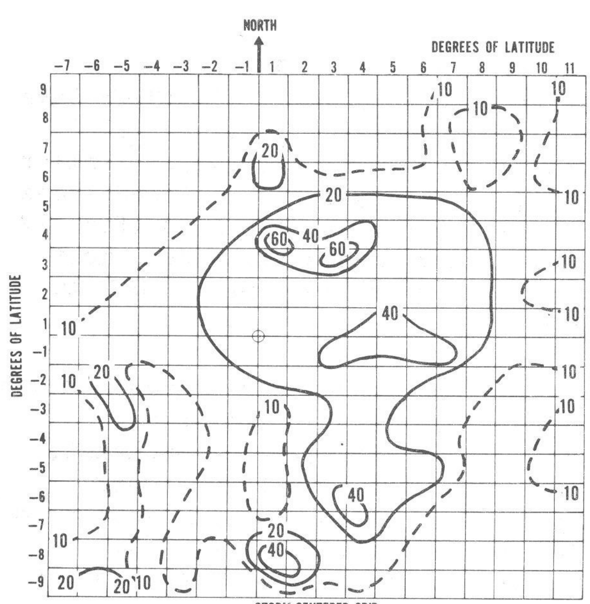

Figure 5. -- Same as figure 4, except this is for class II Lows

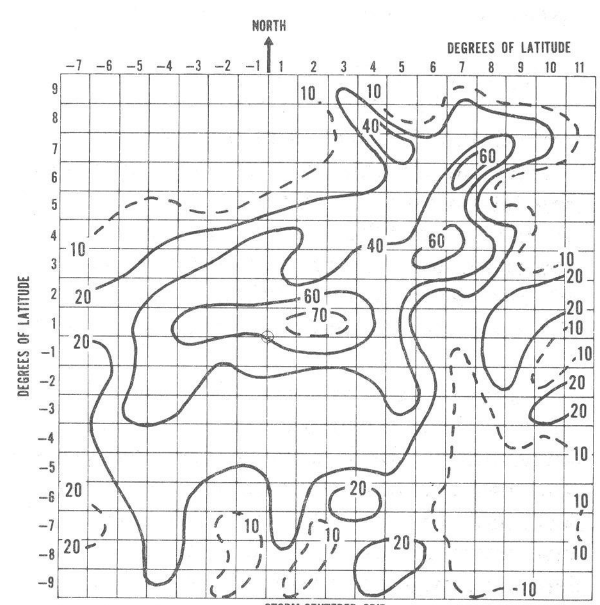

Figure 6. -- Same as figure 4, except this is for class III Lows

B. Frequencies of Precipitation Amounts From 850-Millibar Lows

The frequency of precipitation amounts (expressed as percentages of the 7-day station normals) was separated into four categories: (1) ≥1, (2) 1 through 25, (3) 26 through 100, and (4) >100. Each of the four categories was computed and analyzed for each of the three classes of 850-mb Lows. The analyses are shown in figures 7 through 18.

Figure 7 shows the results for class I Lows and a ≥1 % precipitation category (essentially measurable amounts). Several areas of ≥10 % occur with the largest area to the north and northeast of the Low center and with one isolated area of ≥20 % to the northeast. Beyond these areas, most cells show <20 %. By comparison, class I Lows during winter at 850 mb showed several small areas of 20 %; but spring 850-mb Lows for this class did not reach 20 %.

Figure 8 for class II Lows shows a much larger area of ≥20 % east and northeast of the Low center, with one small isolated center of 20 % to the west. For the fall Lows, the higher frequency areas were more to the north than for Lows in spring and winter. The maxima vary from 20 % (fall) to 55 % (winter) to 40 % (spring).

Figure 9 for class III Lows shows higher frequencies from the northeast to the southwest of the center. The lowest amounts are in the extreme northwest and southern sections of the grid. The maxima for each of the compared seasons are next to the origin of the Low and vary from 75 % (winter) to 60 % (fall and spring).

Figures 10 through 12 give the frequency of occurrence from 1 through 25 % of the 7-day normal precipitation for the three classes of 850-mb Lows. For class I Lows, all values (except a few small isolated areas of ≥10 % along the southern edge and northeast corner) are <10 % (fig. 10). Similar results prevail for class II Lows (fig. 11), with only a few isolated areas of >10 % southeast to northeast of the center. For class III Lows (fig. 12), considerably larger areas of 10 to >20 % are apparent generally over most of the area surrounding the Low center, except for smaller areas < 10 % in the northeast, south, and extreme northwest.

Figures 13 through 15 show the frequency of occurrence of 26 through 100 % of the 7-day normal precipitation. Figure 13 for class I Lows shows generally <10 % except for small areas of >10 % in the extreme southeast, southwest, and northeast corners of the grid. As the Lows become more intense (class II), several slightly larger areas of >10 % appear mainly to the east of the Low center (fig. 14). With class III Lows (fig. 15), a larger area of from 10 to >20 % (with isolated values >40 %) appear in the southwest to northeast portions of the grid.

The frequencies of occurrence of amounts >100 % are shown in figures 16 through 18. Figure 16 for class I Lows and figure 17 for class II Lows each show only one isolated area of >10 %. Again, for the class III Lows (fig. 18), a much larger area of 10 to nearly 30 % is present from the southwest to northeast.

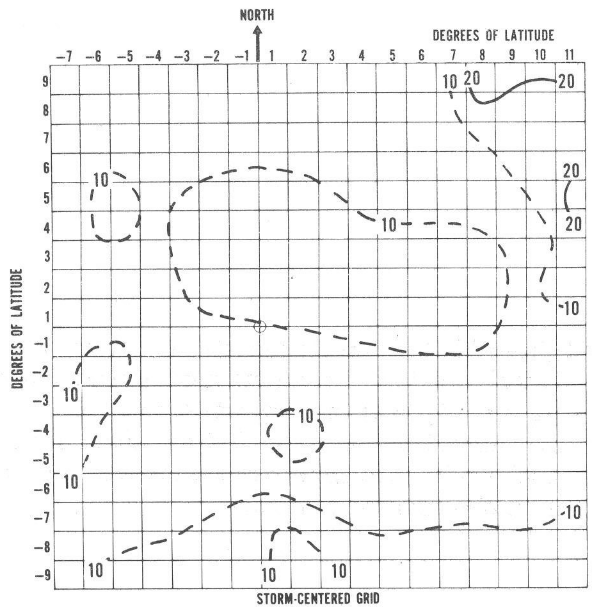

Figure 7. -- Analysis (for class I Lows) of the frequencies of occurrence of precipitation amounts ≥1 % of the 7-day normal (essentially measurable amounts) in the 12-hr periods centered at upper air observation times

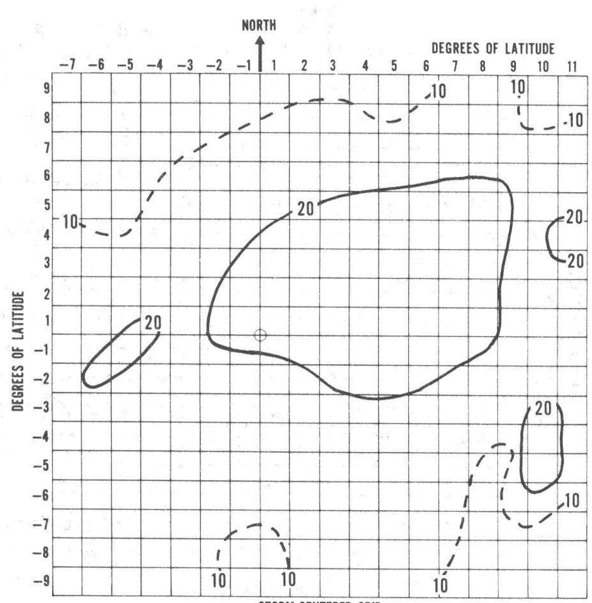

Figure 8. -- Same as figure 7, except this is for class II Lows

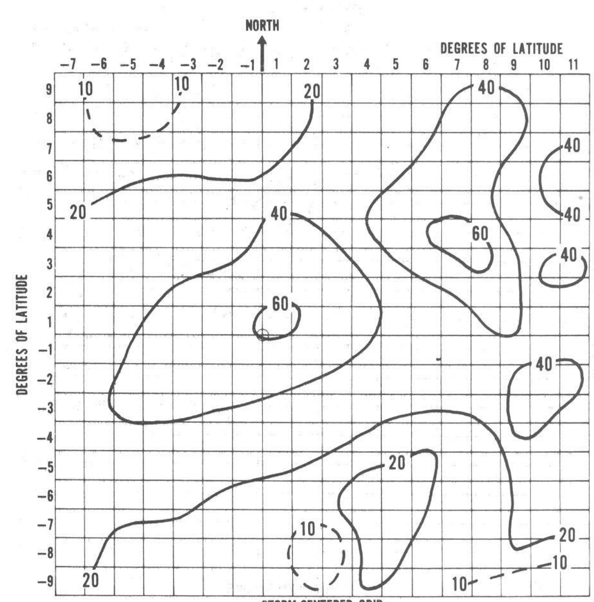

Figure 9. -- Same as figure 7, except this is for class III Lows

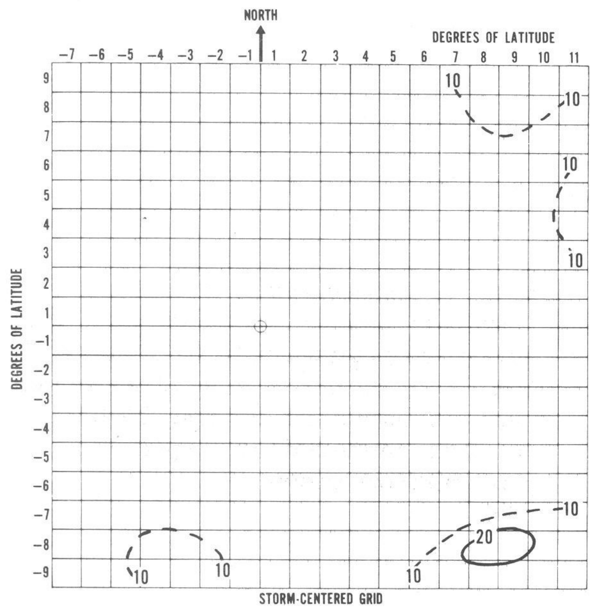

Figure 10. -- Analysis (for class I Lows) of the frequency of occurrence of precipitation amounts from 1 through 25 % of the 7-day normal in the 12-hr periods centered at upper air observation times

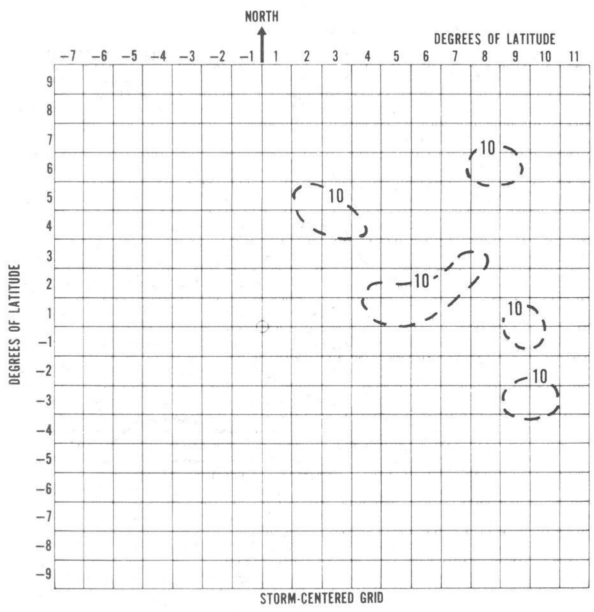

Figure 11. -- Same as figure 10, except this is for class II Lows

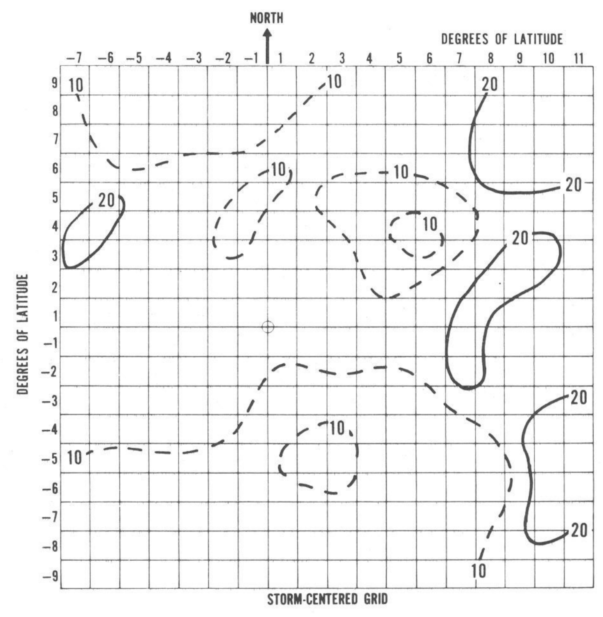

Figure 12. -- Same as figure 10, except this is for class III Lows

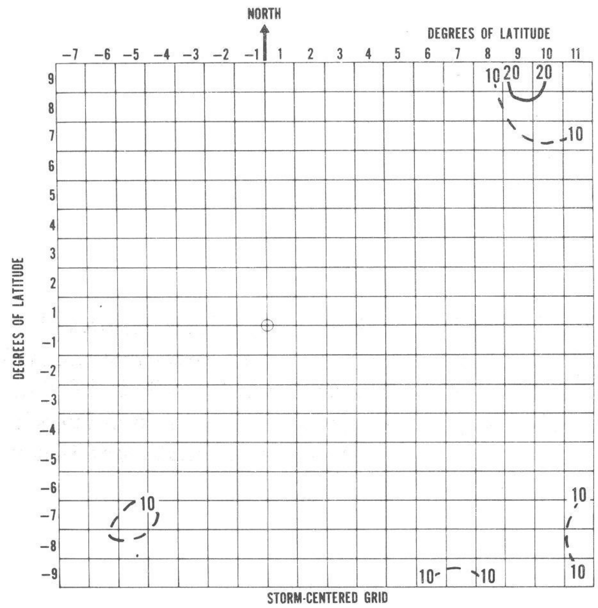

Figure 13. -- Analysis (for class I Lows) of frequency of occurrence of precipitation amounts from 26 through 100 % of the 7-day normal in the 12-hr periods centered at upper air observation times

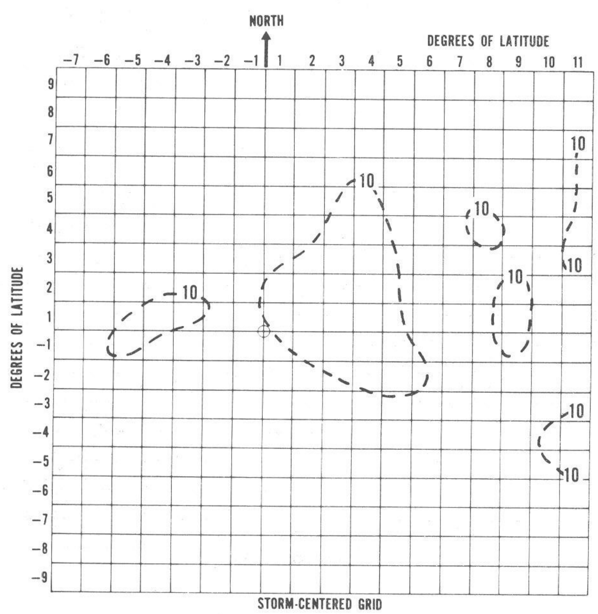

Figure 14. -- Same as figure 13, except this is for class II Lows

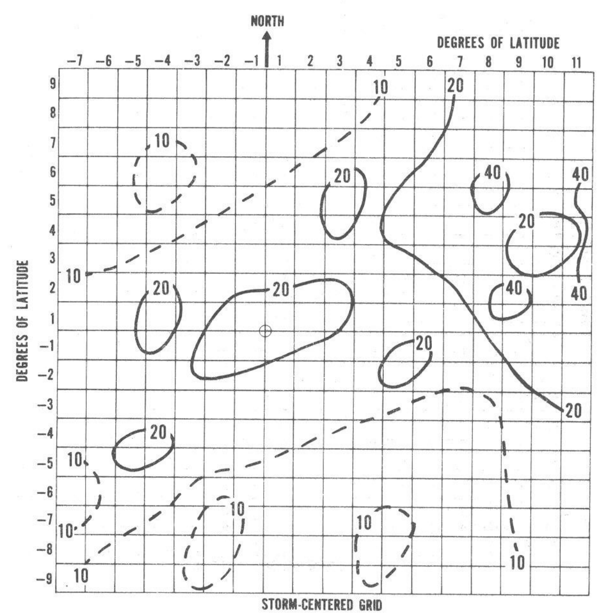

Figure 15. -- Same as figure 13, except this is for class III Lows

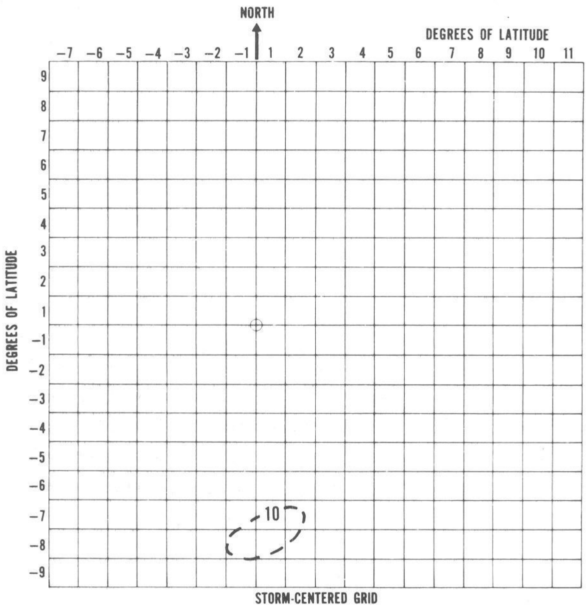

Figure 16. -- Analysis (for class I Lows) of frequency of occurrence of precipitation amounts >100 % of the 7-day normal in the 12-hr periods centered at upper air observation times

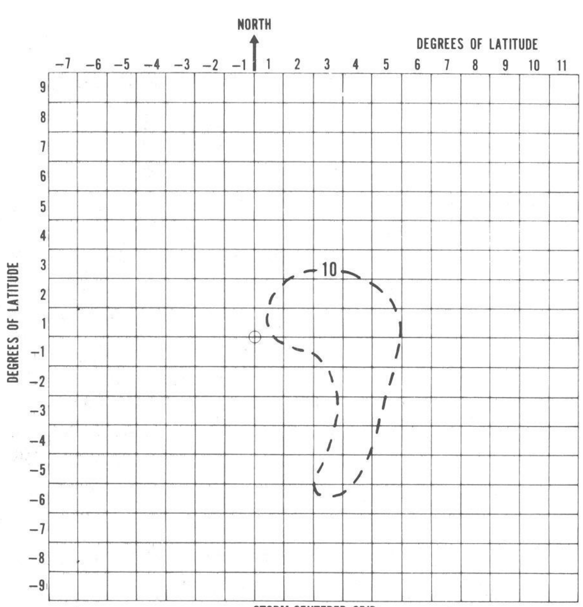

Figure 17. -- Same as figure 16, except this is for class II Lows

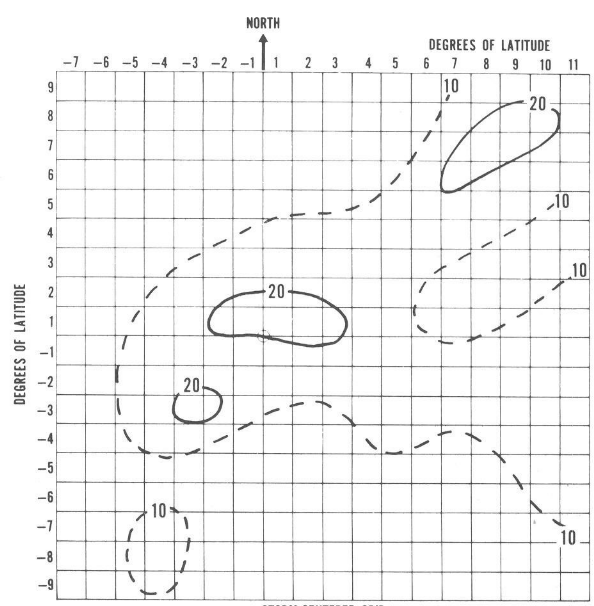

Figure 18. -- Same as figure 16, except this is for class III Lows

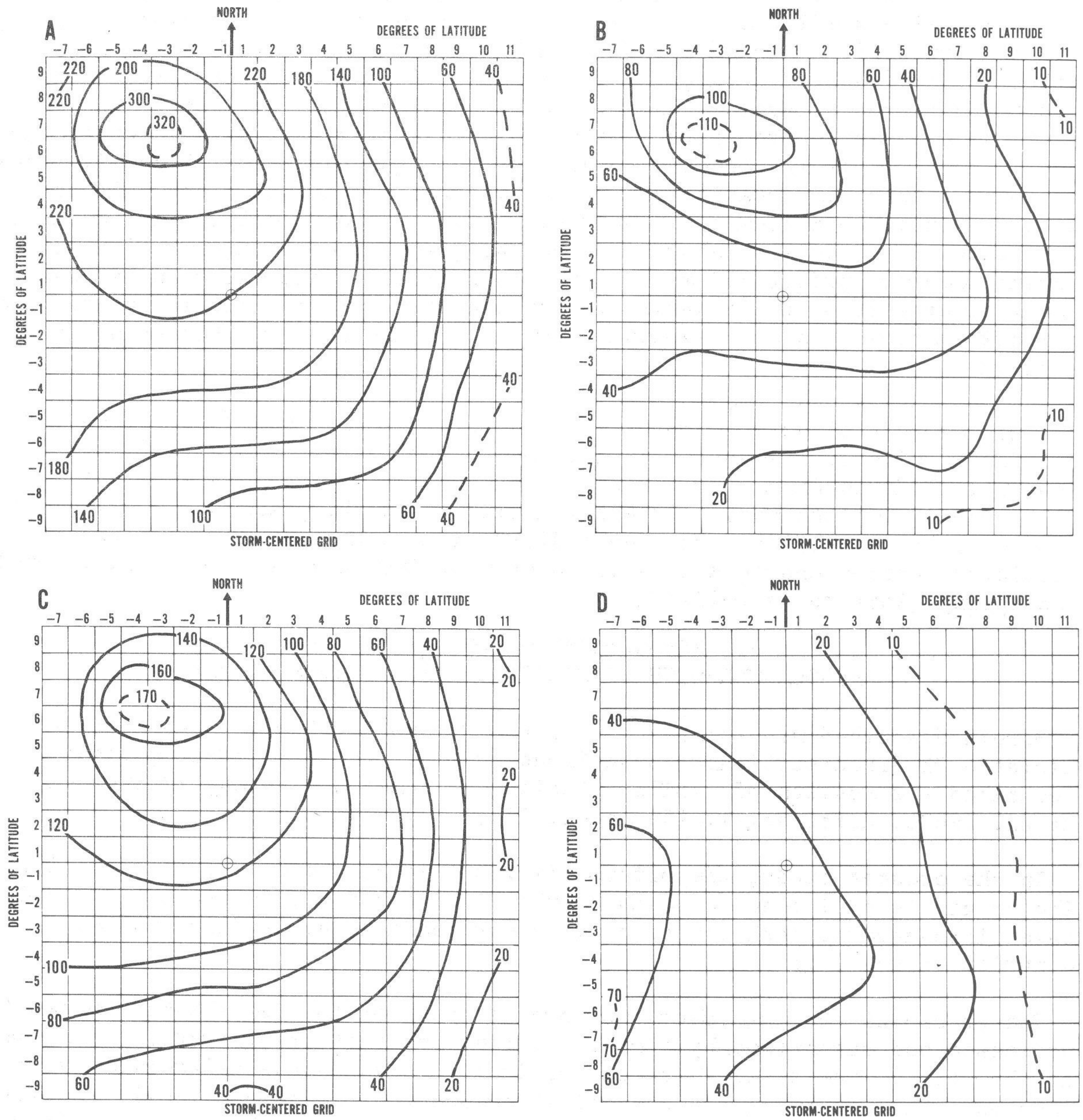

Figure 19. -- Analyses depicting the number of cases per cell. (A) is for all 1,129 upper Lows combined; (B), for the 288 Lows of class I; (C), for the 581 Lows of class II; and (D), for the 260 Lows of class III.

In general, the magnitude of the frequencies is similar to that in spring. The main difference is that more maxima occur to the northeast of the Low center than during spring when all the maxima occur to the northwest of the Low center. The comparison with winter shows a slightly higher magnitude for each class of Lows than during fall. The locations of the winter maxima for class II and III Lows are east of the Low center. In the class II Lows, the magnitude of the frequencies is much lower during fall than during winter. For class III Lows, the magnitudes are less than those for winter; but the differences are not as great as those for class II Lows. The locations of these measurable precipitation frequency maxima vary with respect to the Low center. It is interesting to notice that, for the class II and III Lows, there is a trend in location of the maxima from northeast in the fall to east in winter to northwest in spring. This shift may reflect the increased importance of convective showers in spring. When the average precipitation maxima are compared at 850 mb for the class II and III Lows, we note that the maximum part of the greater average amount occurs in fall and winter compared to spring. In each season, these maxima are at or northeast of the station.

Involved in the above analysis, the number and distribution of cases per cell for the three classes and all classes combined are shown in figure 19 (p. 13). In each case, the larger numbers appear in the northwest, decreasing to the southeast and east. Except for class III, the pattern for all classes is similar to those shown for the individual classes; and the results are similar to corresponding charts for winter at 700 mb (Jorgensen et al. 1966) and spring (Korte et al. 1972).

4. FREQUENCIES OF PRECIPITATION ASSOCIATED WITH LOWS RELATIVE TO FIXED STATIONS

Herein described are the results at the 850-mb level with respect to the isolated 35 fixed stations (table 3, appendix). Earlier investigations described the results of similar studies in winter and spring (Jorgensen et al. 1967b; Korte et al. 1969 and 1972).

In the present study, the origin (fig. 2B) is at the center of the grid. The origin is positioned at each of the 35 stations. This stationary grid takes into account both the topography surrounding the station and the dynamics of the storm.

The precipitation data from the three classes of Lows at the 850-mb level were processed and summarized by computer. The amount of precipitation recorded at the station was assigned to the grid cell in which the related Low was located. The percentage of precipitation occurrences in each cell represents the probability of precipitation at the station when the Low was in this cell.

Station charts give the probability patterns of the occurrence of measurable precipitation at each station for each class of Lows. These patterns were obtained by smoothing the data in a manner similar to that described by Petterssen (1956) whereby data are averaged within overlapping squares of variable sizes. The resulting averages were located at the center of each square. These data were smoothed and the isopleths were drawn objectively by computer. The outermost centers of the overlapping squares were all located on the dashed boundary lines as shown on each station chart in the appendix. The area they enclose is within the heavy black lines outlining the borders of the fixed grid (fig. 2B). The grid is centered on the station shown by the black dot (origin) on each chart in the appendix. Three charts are shown for each of the 35 stations analyzed, one chart for each class of Low; the charts are numbered in the same manner used in Korte et al. (1972). The approximate center of any area where less than five observations occurred in an overlapping square is labelled on the station chart as "Sparse data." No frequencies of measurable precipitation or related averages were considered if less than five observations were available for analysis.

Average precipitation amounts in inches were obtained by computer within each overlapping square and assumed to be associated with the corresponding frequency (probability) of measurable precipitation (>0.01 in.). These amounts of average precipitation and related probabilities were tabulated objectively by the computer and grouped in probability contour intervals as shown in the upper right corner of each station chart.

The map on which each station chart is presented is a Lambert Conformal Projection (standard parallels at 30°N and 60°N), U.S. Department of Commerce, Weather Bureau (now National Weather Service) map, form 1514, scale 1:10,000,000. Because of the map projection used, the grid is approximately square (fig. 2B).

5. RESULTS OF SELECTED STATION INVESTIGATIONS

The probability of precipitation charts (appendix) for the 35 stations show both interesting differences from and similarities to the earlier studies. A general inspection of all the charts shows that highest probability of precipitation at the 850-mb level occurs with the class III Lows. However, it was noted that, at 11 stations, class II Lows show almost as high a probability of precipitation as class III Lows. Several stations have class I Lows with almost as high a probability of precipitation as the other two categories. This is particularly true for stations with low values of frequencies in all classes, such as Iron Mountain and Parker Reservoir.

In general, the magnitude of the frequency maxima during fall is similar to those found in winter and spring (Korte et al. 1969 and 1972). In New Mexico, Crownpoint and Farmington generally show somewhat higher maxima during fall. Except for the class I Lows in Mogollon, N. Mex., and the class II Lows in Tucson, Ariz., other values at these two stations are higher than those in spring but about the same as those during winter. On the class III charts, three stations in California (El Centro, Iron Mountain, and Parker Reservoir) as well as Tonopah, Nev., and Yuma, Ariz., all generally show much lower frequencies than during spring and winter. It is difficult to determine any consistent difference in the location of the frequency maxima for the stations in the fall. In this study, a few stations were selected as examples and are discussed briefly. The local effects on synoptic weather patterns at some of these stations were investigated earlier (Williams 1967). He indicated several reasons for the considerable variety in weather at some of the stations presented in the appendix.

Craig, Colo. (Charts 5-I, 5-II, and 5-III)

The frequency values for class I Lows are about as high as those in class II and only slightly less than those in class III. The frequency maxima for class I Lows are mainly to the southwest of the station, to the south and east for class II, and to the east for class III. This indicates that the weaker lows (class I and II) are to the southwest and the strong Lows (class III) are confined to the eastern area. Frequency values are generally lower than those in spring (excluding class I) and winter.

El Centro, Calif. (Charts 9-I, 9-II, and 9-III)

The frequency values for the maxima centers are low for all three classes, mainly ≤40 %. The Lows in classes I and II are to the south and southwest while the Lows in class III are found more to the east and southeast of the station. Similar patterns generally occur for Iron Mountain, Calif. Most values are definitely lower in class III than those during spring and winter. Generally for winter, spring, and fall, the pattern appears to show that Lows off southwest California are associated with higher probabilities of precipitation in this region.

Salt Lake City, Utah (Charts 30-I, 30-II, and 30-III)

The frequency maxima (mainly ≤20 %) for class I Lows are generally spread over all directions, with slightly higher values in the extreme northeast. The frequency maxima for the class II Lows are still low except for slightly higher values (40 %) to the west. The frequency values are generally higher for Lows in class III (60-80 %) and the maxima are located to the southeast and northeast of Salt Lake City. In general, for class III Lows, the frequency maxima are similarly located as those during spring and winter.

Ogden, Utah (Charts 20-I, 20-II, and 20-III)

The values of the frequency maxima are about the same for Lows in all three classes. The location of the similar frequency maximum is to the south of the station for class I, to the northwest for class II, and to the northeast for class III. Thus the important weak Lows (class I) are to the south, and the important intermediate (class II) Lows are to the northwest while the important strong (class III) Lows are to the northeast of Ogden. The values of the frequency maxima for class III Lows are about the same as those in spring and somewhat less than those in winter while the values of the frequency maxima for class II Lows are lower than those in winter and spring. The values of the frequency maxima for class I Lows are definitely higher than those in winter and spring. The location of the frequency maximum for class I Lows is more to the southeast.

Flagstaff, Ariz. (Charts 13-I, 13-II, and 13-III)

The class I fall Lows indicate probability maxima of 30 % to the northwest over eastern Nevada and 40 % over southern Arizona to the south. In winter, such Lows indicated <40 % to the northeast. In spring, the probabilities did not reach 20 %; in winter, the probabilities did not reach 40 %. In each case, the probabilities are low for weak Lows. The class II Lows show maxima to the south and west of the station to be <60 % for fall. This can be compared to an area <90 % west of the station during winter and to an area <70 % northeast of the station during spring. The class III Lows show maxima during fall and spring from the northeast to the southwest to be generally <90 %. The winter maxima were <90 % northeast and <95 % northwest of the station. An axis of high probability is oriented from the northeast to the southwest, centered through the station during the fall and to the north during spring and winter.

Ouray, Colo. (Charts 21-I, 21-II, and 21-III)

For fall, winter, and spring, high probabilities exist for all classes of Lows. In the fall, the probability maxima range between 50 and 60 % for the weaker class I Lows to nearly 80 and 90 % for the stronger class III Lows. Ouray is a mountain station at an elevation of 7,740 ft; thus orographic effects are a likely factor in the high probabilities of precipitation.

Tonopah, Nev. (Charts 32-I, 32-II, and 32-III)

This is another mountain station at an elevation of 5,426 ft. In general, the station is situated on the leeward side of the Sierra Nevada Mountains. In this case, the orographic effects are the opposite of those noted at Ouray and result in a drier climate. In fall, winter, and spring, the probability maxima range from ≤10 % for the weaker class I Lows to nearly 40 and 60 % for the stronger class III Lows.

The average precipitation value associated with each probability interval may be used as a first estimate of the quantitative precipitation to be expected. These values are tabulated on each chart in the appendix.

6. APPLICATION OF THE DERIVED CHARTS

As shown in earlier studies (Jorgensen et al. 1967b; Korte et al. 1969 and 1972), the probability charts (appendix) for upper level Lows at a station could be used as a forecast aid and for weather modification research. The charts give a first estimate of the average measurable precipitation and the related probability from Lows at the 850-mb level during fall.

We suggest that the charts in the appendix be applied, using the following procedures and realizing that the forecaster's best judgment is always an overriding consideration as indicated by the National Weather Service Western Region (1971).

1. Using numerical prognostic charts transmitted over facsimile or other sources of forecast information, plot the corresponding position of the major Low within the grid area centered on the station.

If more than one concurrent Low exist in the grid area at a selected level,

(a) choose the preferred low as the deepest one present.

If these Lows are of equal intensity,

(b) select the Low nearest to the station in the grid area.

If both Lows are equidistant from the station,

(c) select the most persistent Low that is expected to affect the station and be in the grid area for the longest period.

2. Using the appropriate normal (mean) height maps (Korte 1971) and the forecast position of the Low center, obtain the DN (departure from normal) height.

The position of the upper Low is located on the appropriate normal chart for the given date, and the normal height at this point is read off. For additional accuracy, these normal heights may be interpolated. The difference between the observed and normal heights (observed minus normal) in meters gives the values (Korte and Colson 1972).

3. Using table 1, determine the intensity class of the selected Low and then obtain the related probability. The average amount of precipitation tabulated for each probability contour interval is available from the corresponding intensity class chart for each station.

The derived charts have been provided to the headquarters of the Western Region of the National Weather Service in Salt Lake City, Utah, for operational tests and evaluation. Similar charts have been derived for the winter (Jorgensen et al. 1967b and Korte et al. 1969) and spring (Korte et al. 1972). The summer season may require a different approach because considerable precipitation in the Plateau Region may occur from convective activity unrelated to a Low center.

7. CONCLUSION

The results of this investigation suggest considerable variations among winter, spring, and fall. The seasonal precipitation probabilities differ enough so that they should be treated separately.

Most of the production of the types of synoptic climatological charts presented can now be done rapidly by the TDL data-processing program. This technique may give improved results over flat terrain such as in the Mid-western States. In any related future studies, the utility of the charts may be increased if the moisture characteristics of the atmosphere now forecast by the National Meteorological Center of the National Weather

Service are included in the Lows investigated. Then the Lows could be categorized not only according to their intensity but also according to their trend in mean relative humidity. Such data were not forecast earlier and therefore could not be utilized when these studies began. In addition, the available software from this technique can be adapted to other atmospheric circulation characteristics such as vorticity centers, vertical motion centers, isallobaric centers with respect to troughs, etc. The computer technology established by the TDL can accomplish this much easier and better than it can be done manually.

ACKNOWLEDGMENTS

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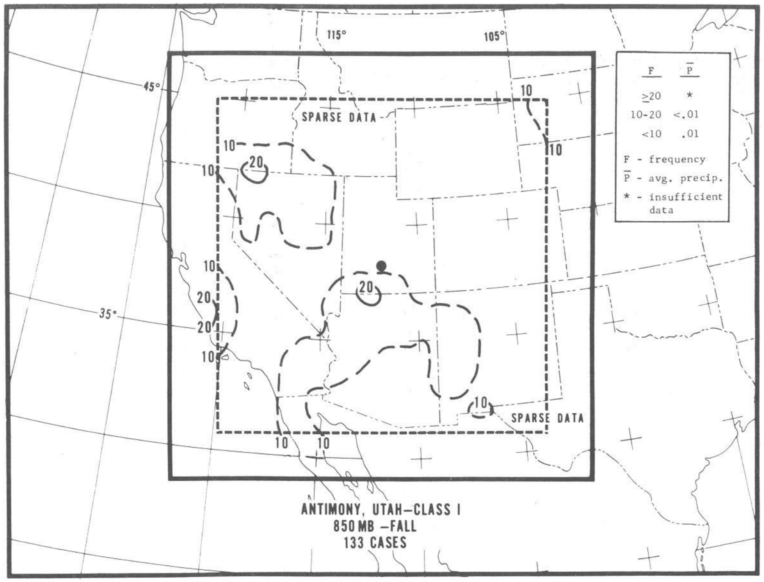
APPENDIX: OPERATIONAL CHARTS

The following information from our earlier study (Korte et al. 1969) is also applicable here. In the Intermountain West with its varied and rugged terrain, each station will exhibit a unique topographic effect. As shown in this investigation, the patterns giving the frequency of occurrence of precipitation for several stations show significant individual station characteristics. To illustrate further these characteristics and to make station charts available for operational use, we have prepared charts for a selection of 35 stations out of 157 for which data are available. These stations have been chosen because of the completeness of their precipitation records and our desire to give a sampling of the various parts of the station network (fig. 1).

Charts for fall at the 850-mb level for each of the three intensity classes, I, II, and III, are given for each of the 35 stations (table 3).

Table 3.--Selection of 35 stations in the Intermountain West

Chart	Station	Station elev. (ft)	Chart	Station	Station elev. (ft)
1	Antimony, Utah	6,460	19	Mogollon, N. Mex.	6,795
2	Boise, Idaho	2,842	20	Ogden, Utah	4,280
3	Bryce Canyon, Utah	7,900	21	Ouray, Colo.	7,740
4	Cedar City, Utah	5,980	22	Parker Reservoir, Calif.	738
5	Craig, Colo.	6,280	23	Phoenix, Ariz.	1,083
6	Crownpoint, N. Mex.	6,978	24	Pocatello, Idaho	4,444
7	Durango, Colo.	6,550	25	Prescott, Ariz.	5,014
8	Eagle, Colo.	6,497	26	Price, Utah	5,580
9	El Centro, Calif.	30	27	Reno, Nev.	4,404
10	Elko, Nev.	5,075	28	Rifle, Colo.	5,319
11	Ely, Nev.	6,257	29	Rock Springs, Wyo.	6,367
12	Farmington, N. Mex.	5,395	30	Salt Lake City, Utah	4,220
13	Flagstaff, Ariz.	6,993	31	Silver Lake Brighton, Utah	8,700
14	Grand Junction, Colo.	4,849	32	Tonopah, Nev.	5,426
15	Green River, Utah	4,070	33	Tucson, Ariz.	2,584
16	Iron Mountain, Calif.	922	34	Winslow, Ariz.	4,880
17	Jackson, Wyo.	6,244	35	Yuma, Ariz.	199
18	Las Vegas, Nev.	2,162			



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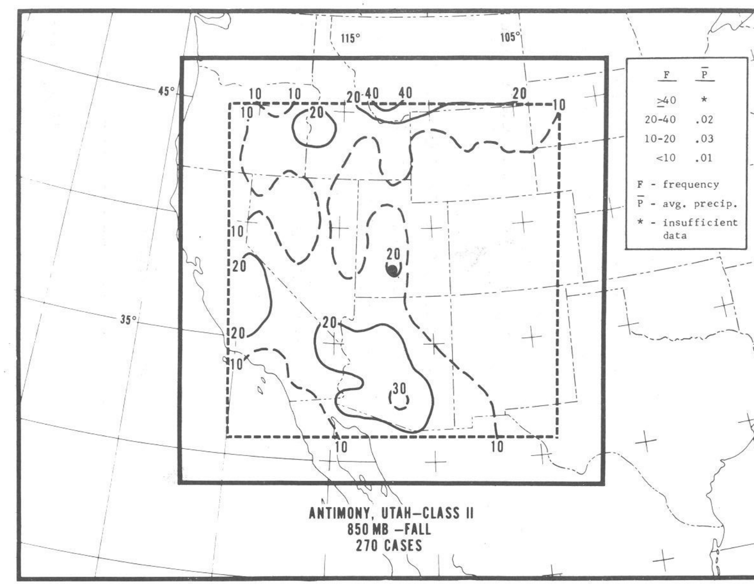

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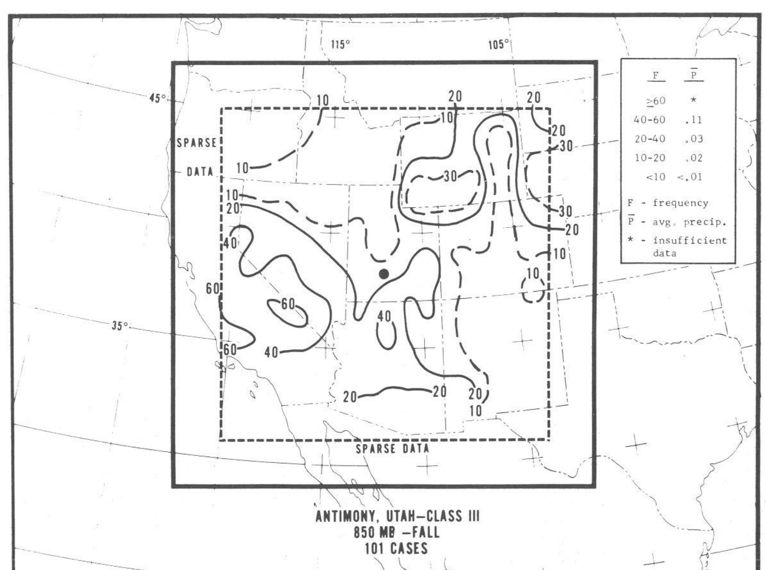

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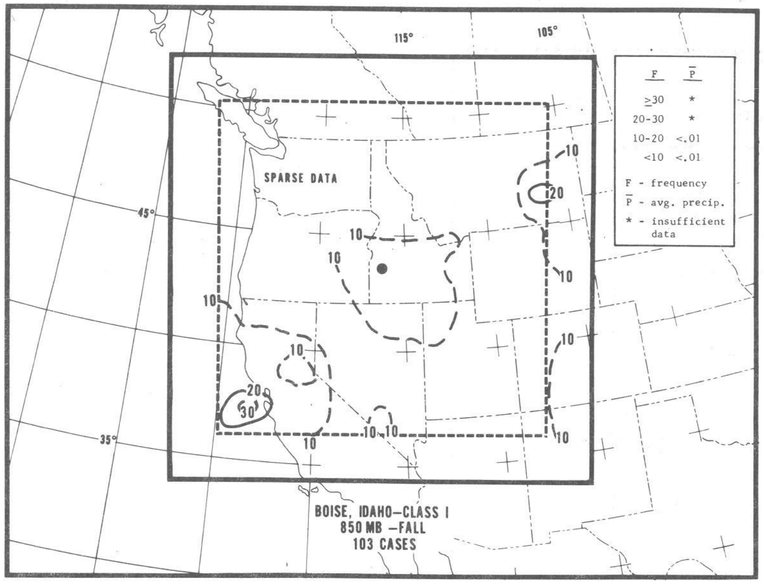

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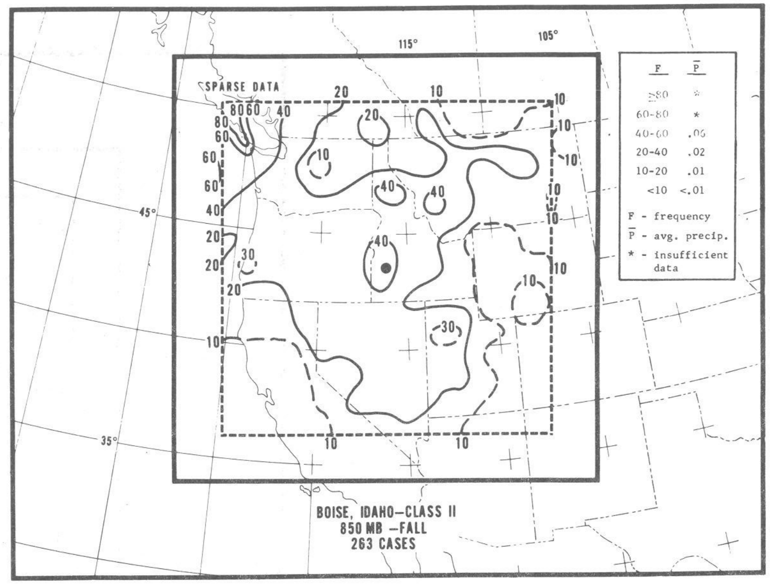

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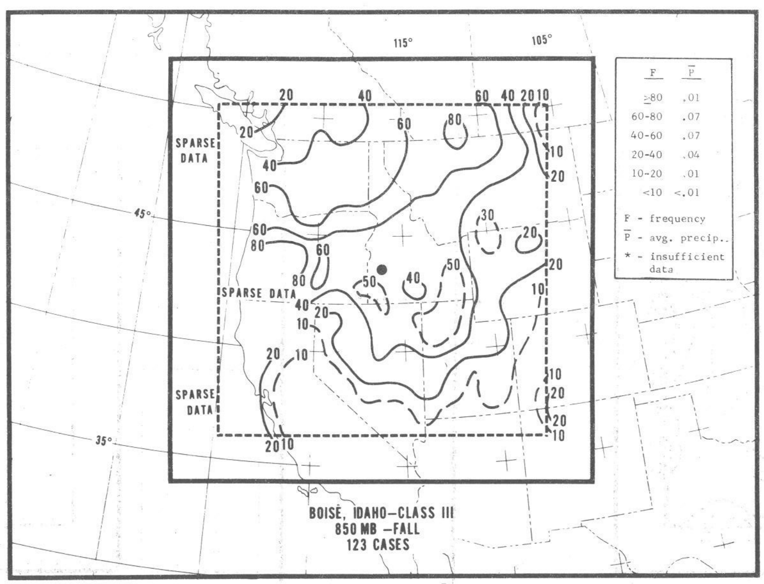

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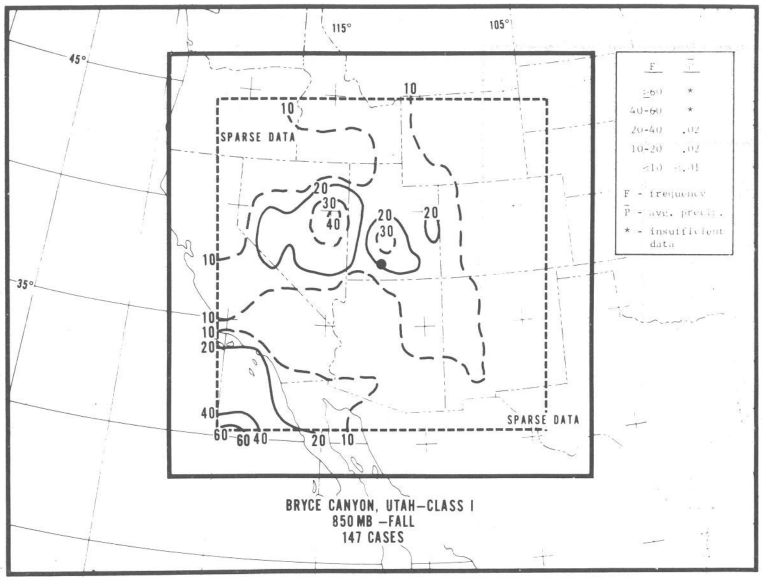

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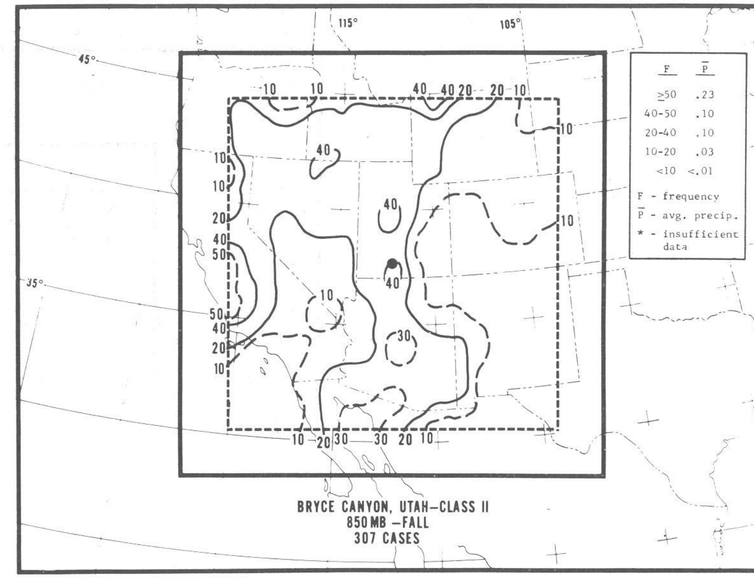

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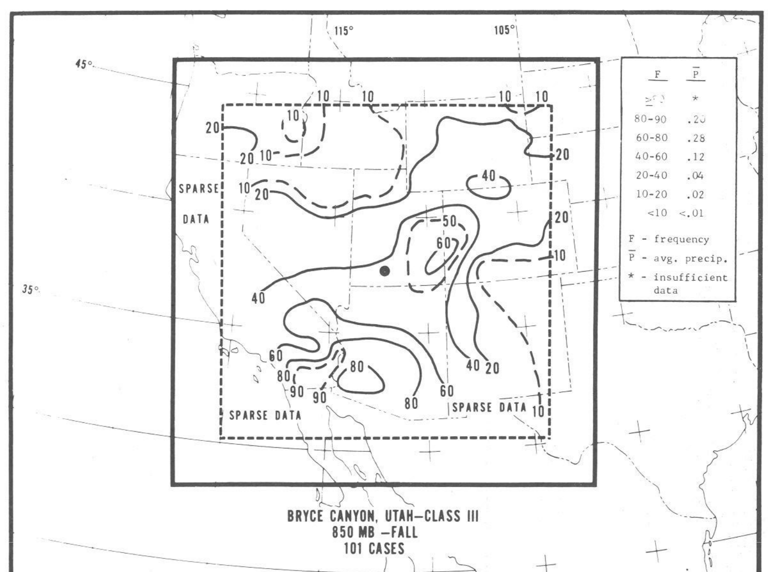

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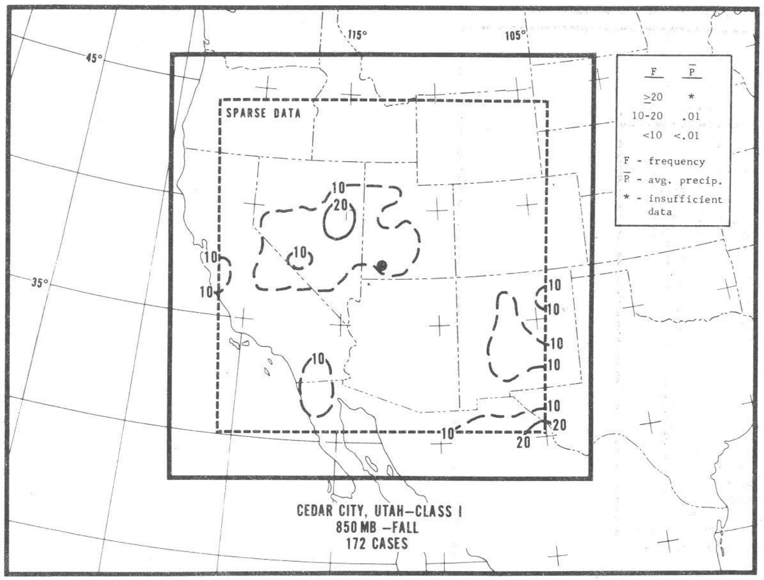

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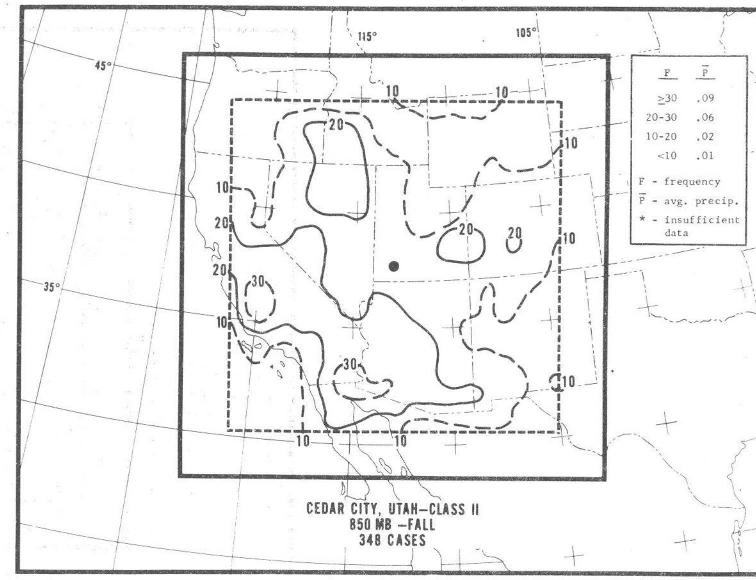

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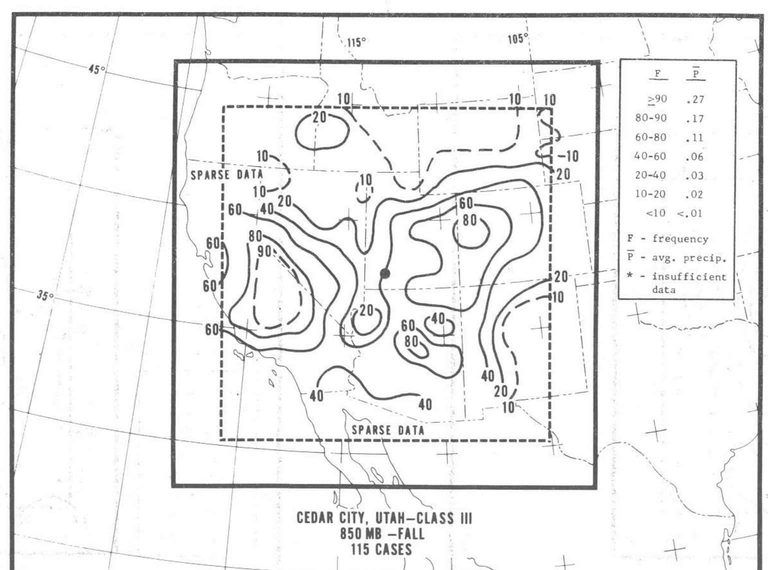

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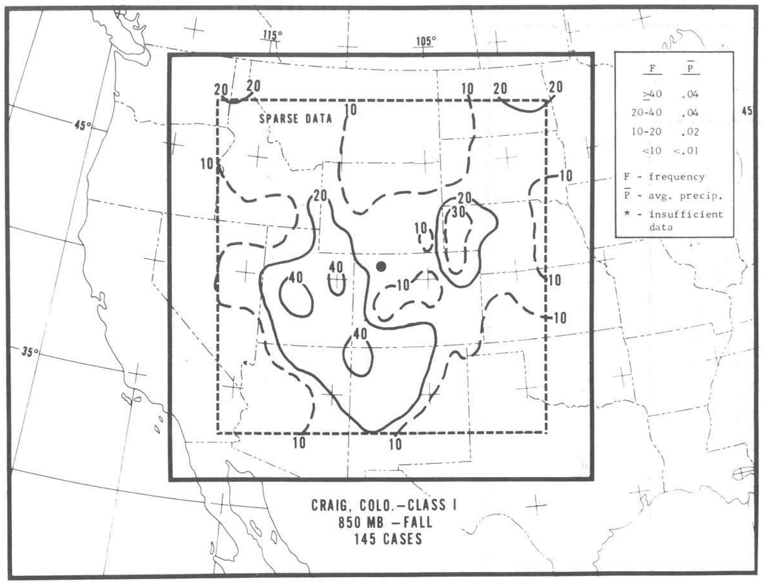

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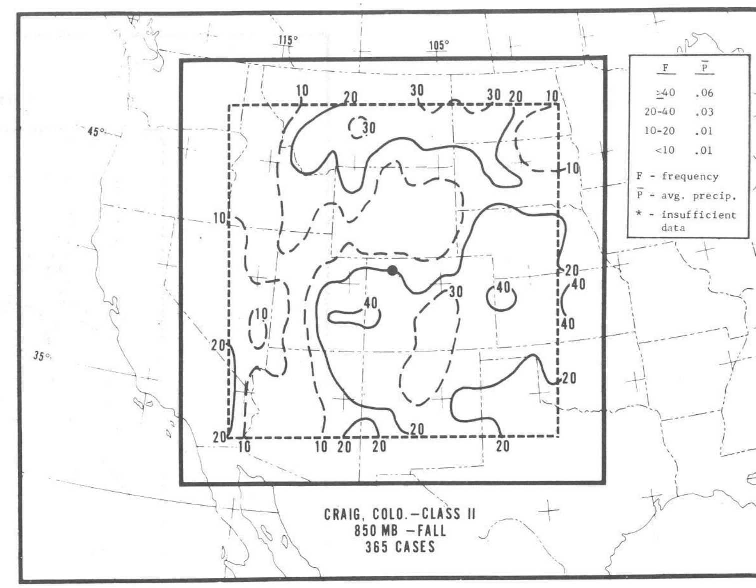

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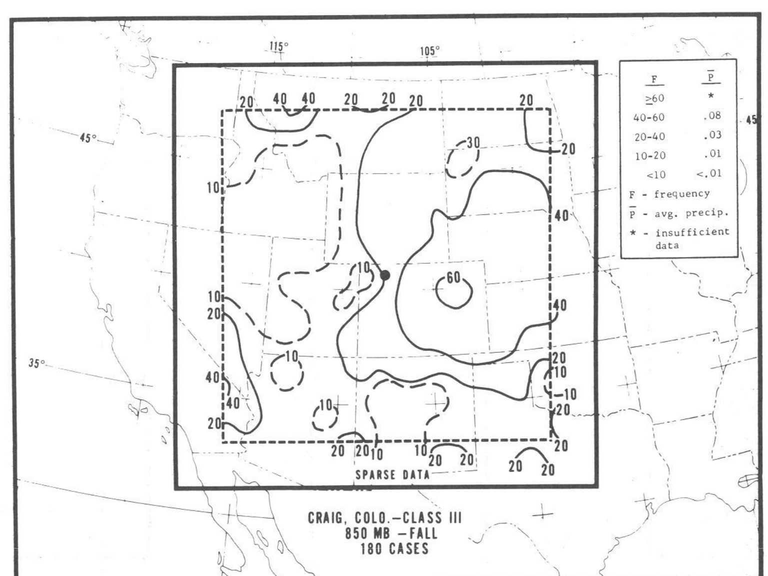

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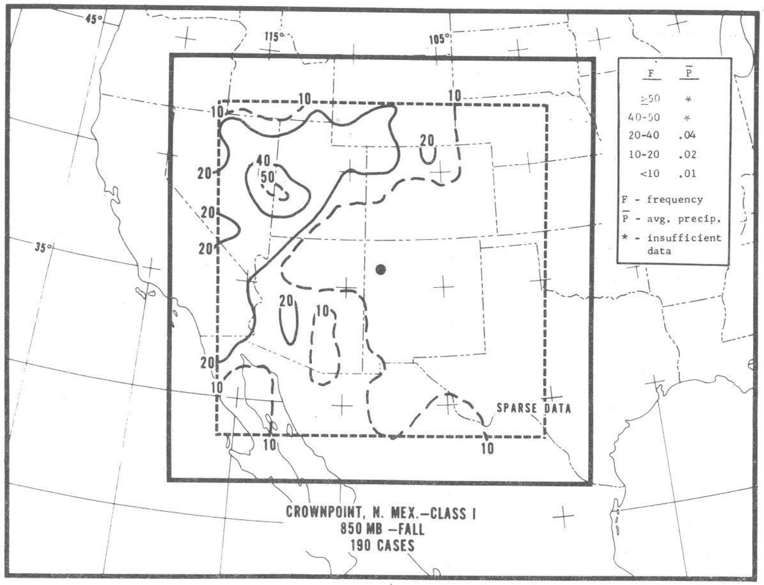

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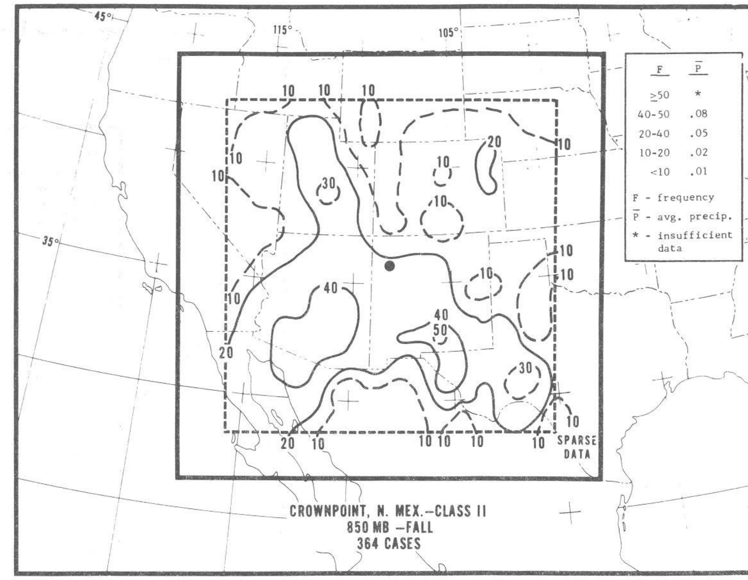

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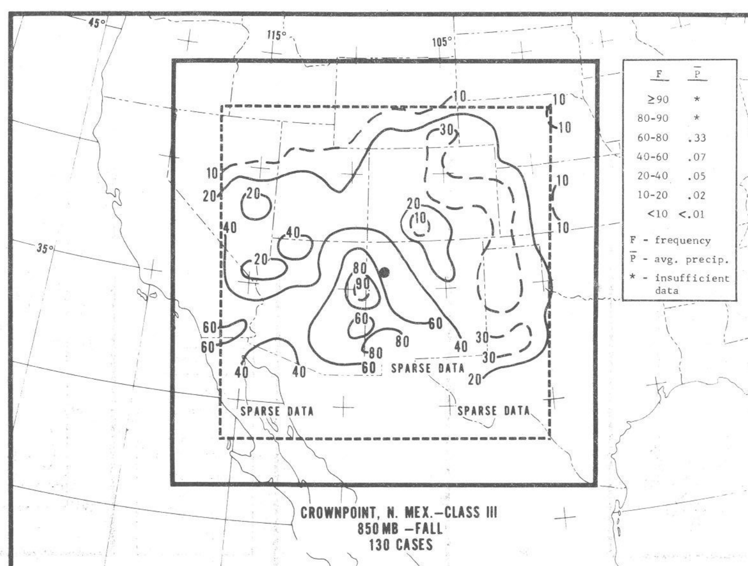

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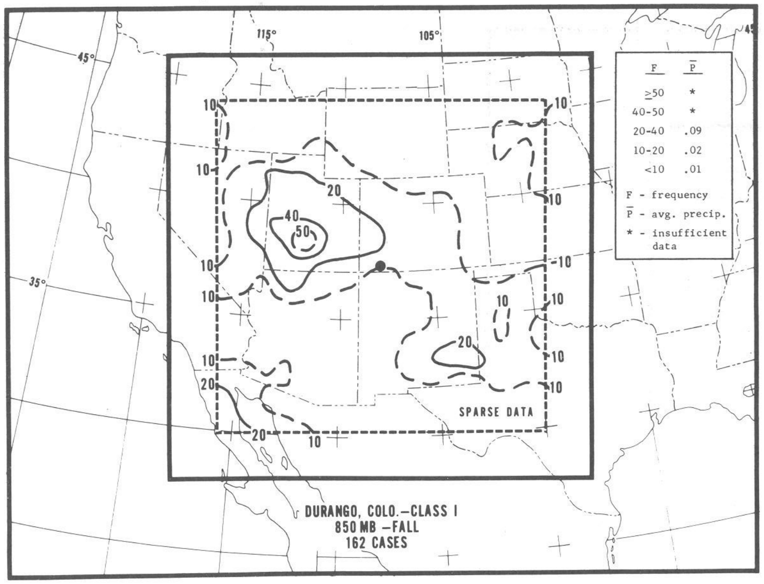

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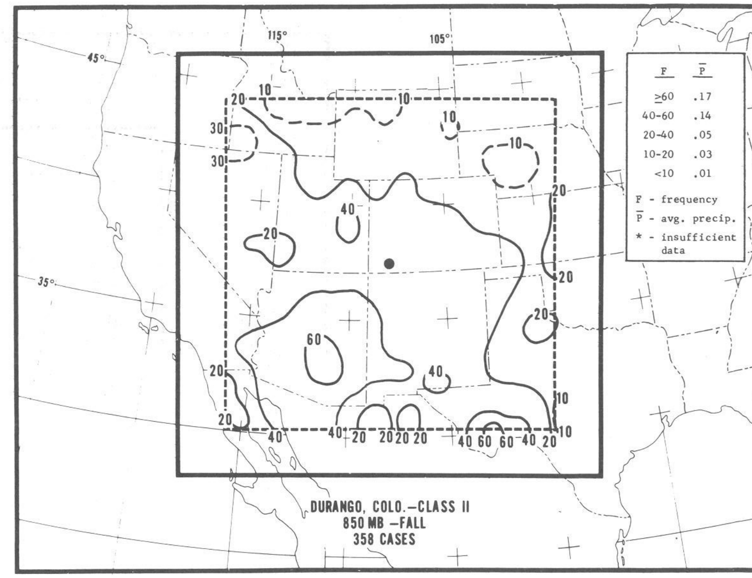

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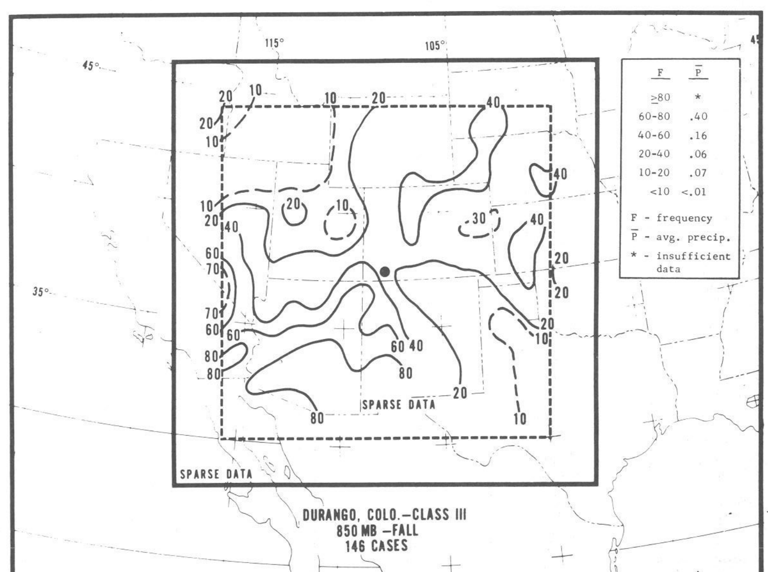

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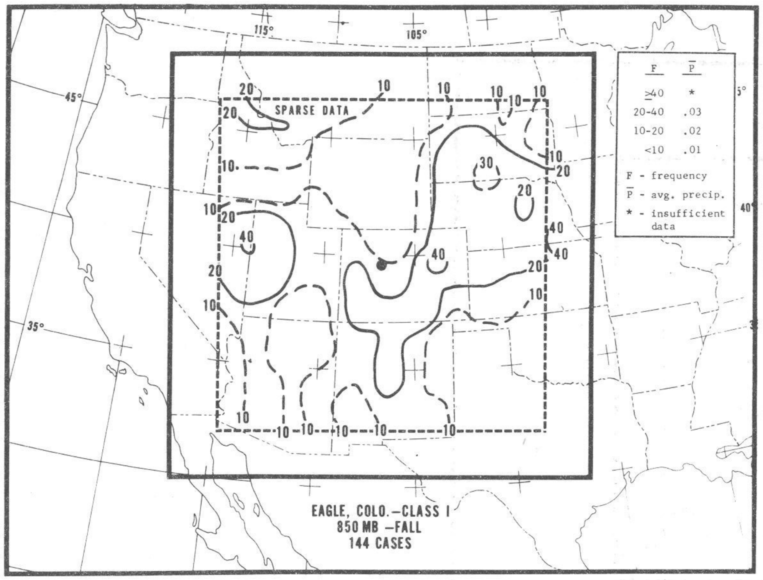

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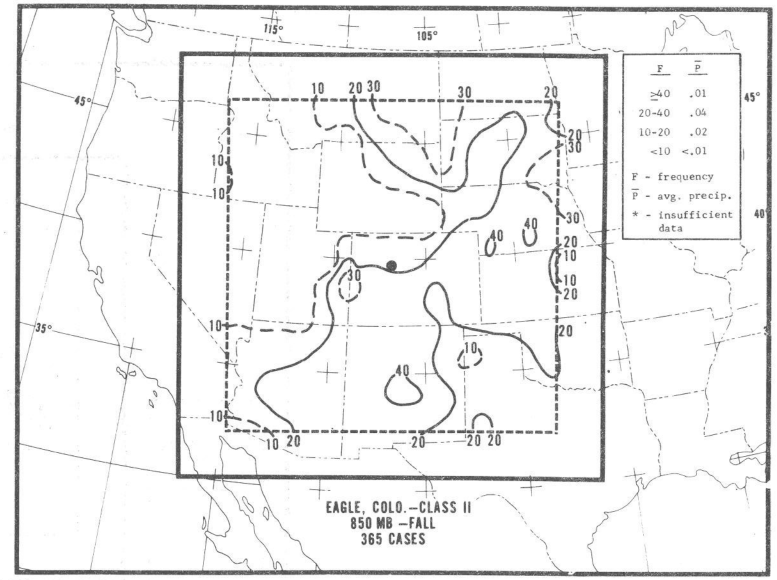

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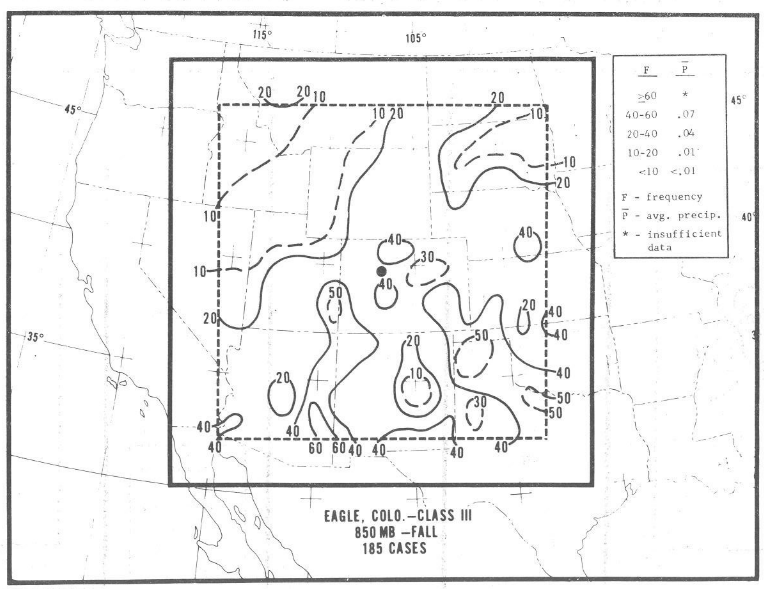

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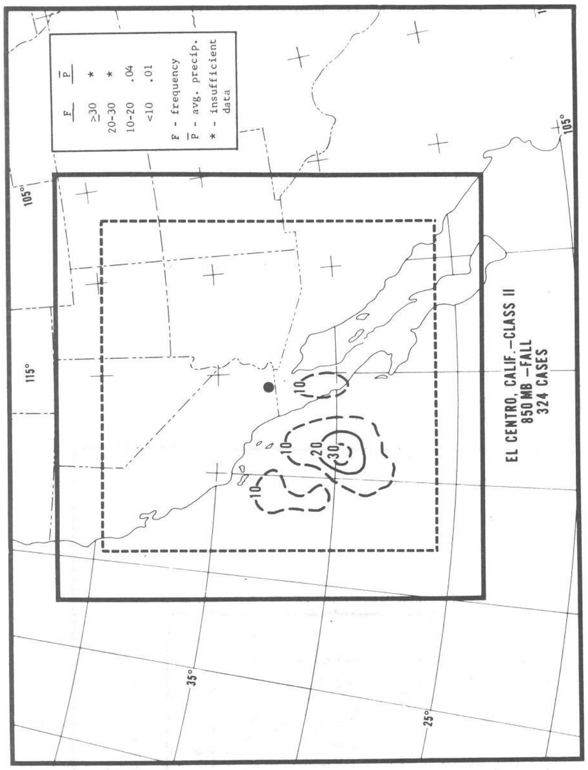

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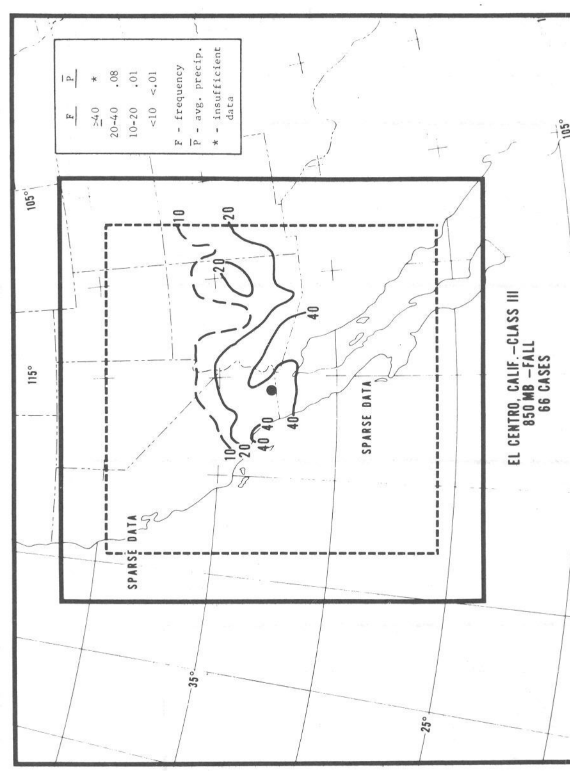

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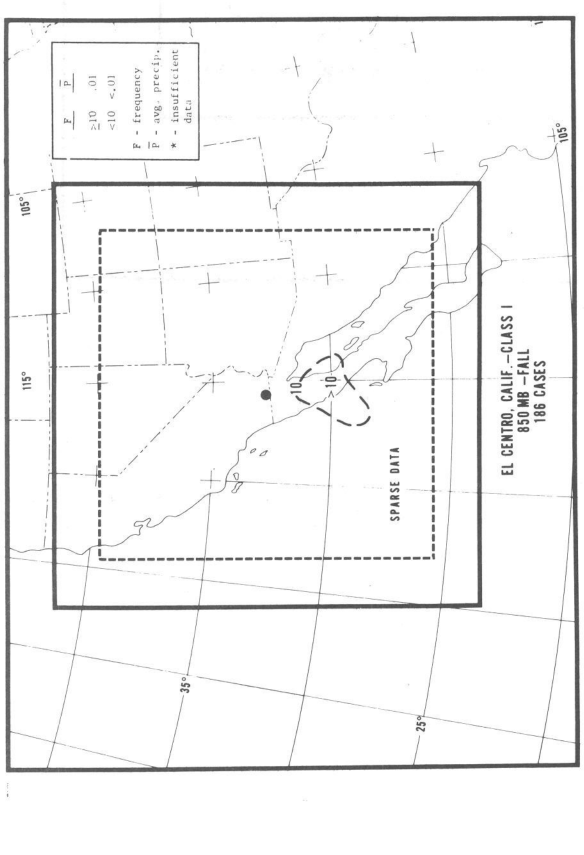

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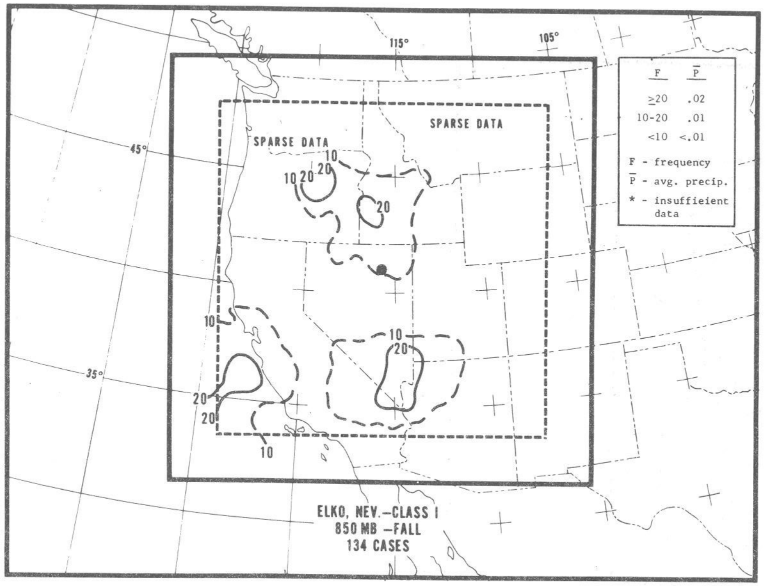

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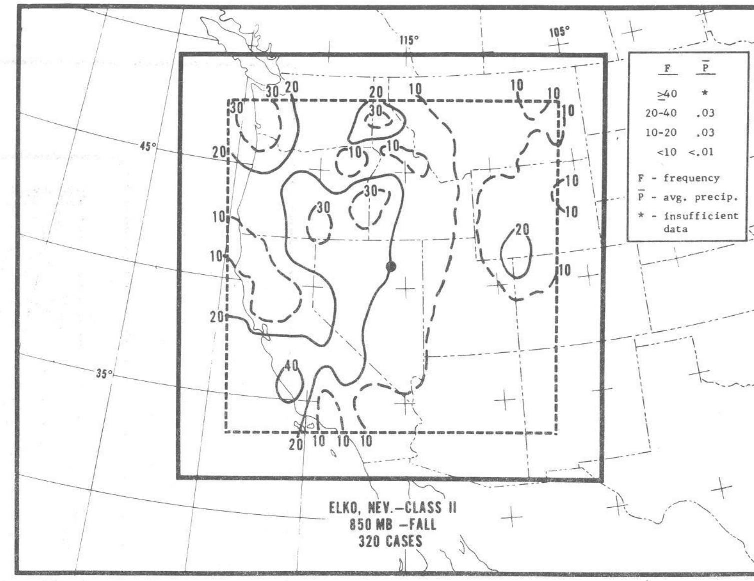

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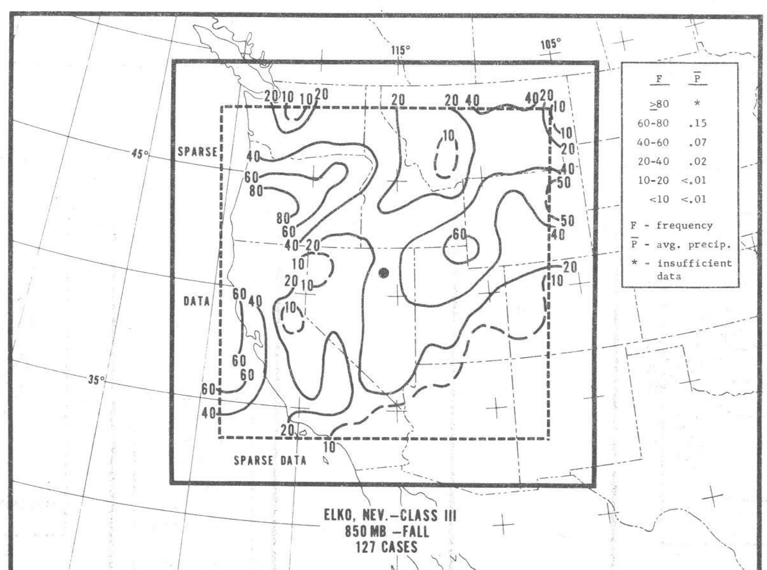

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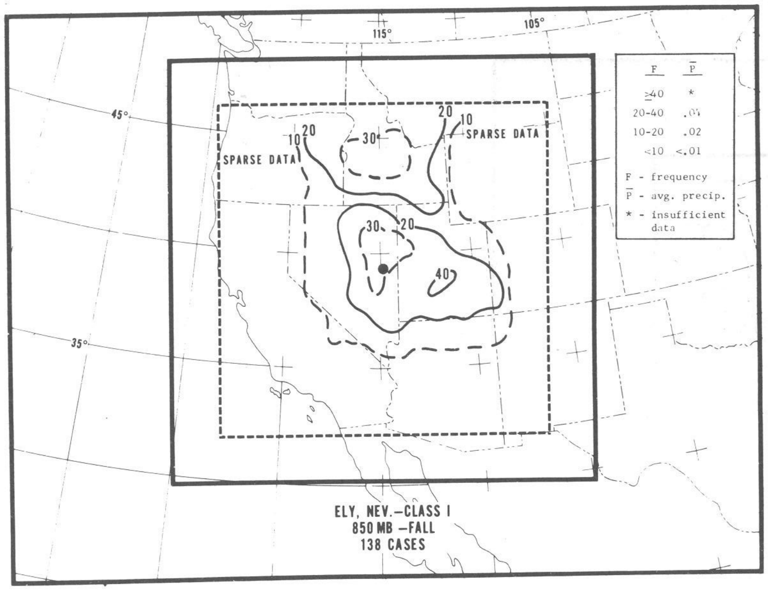

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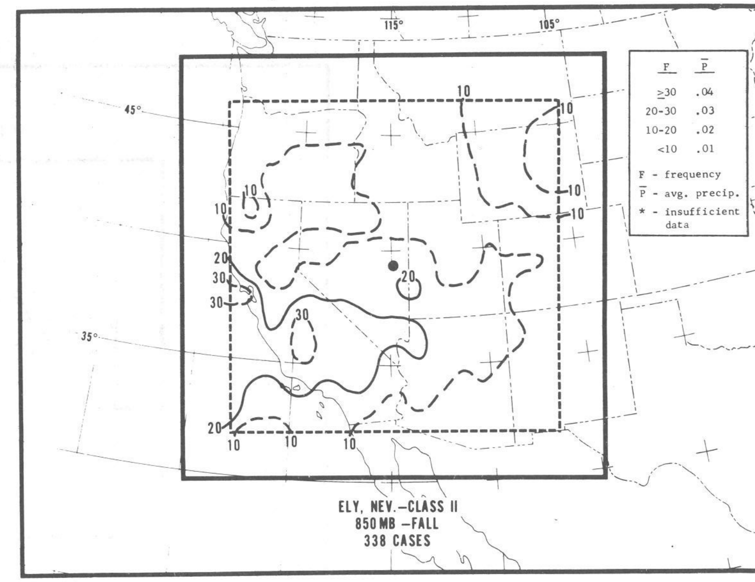

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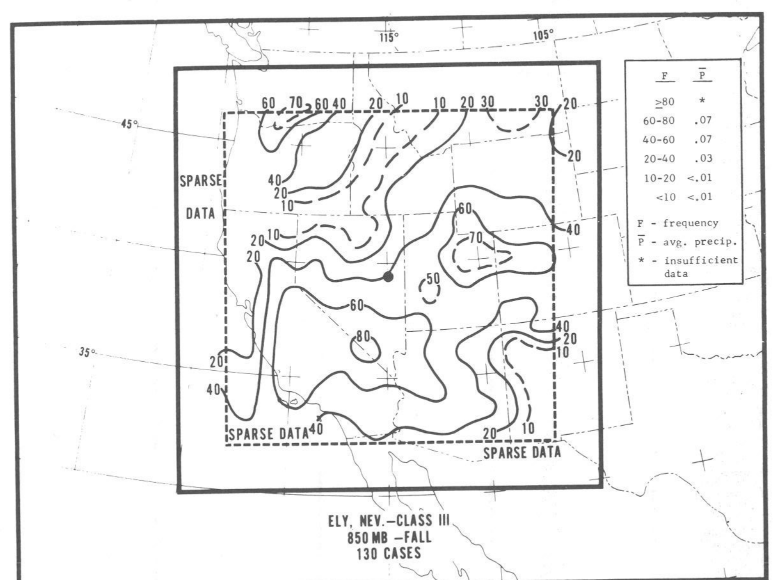

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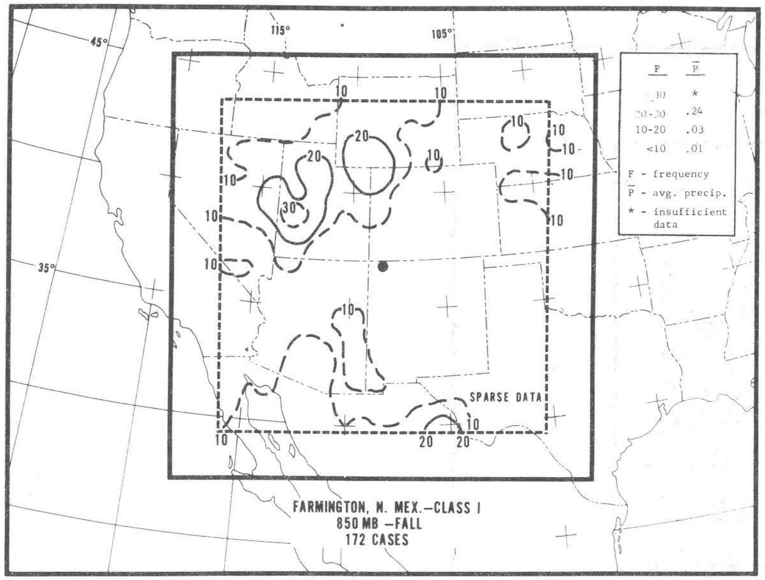

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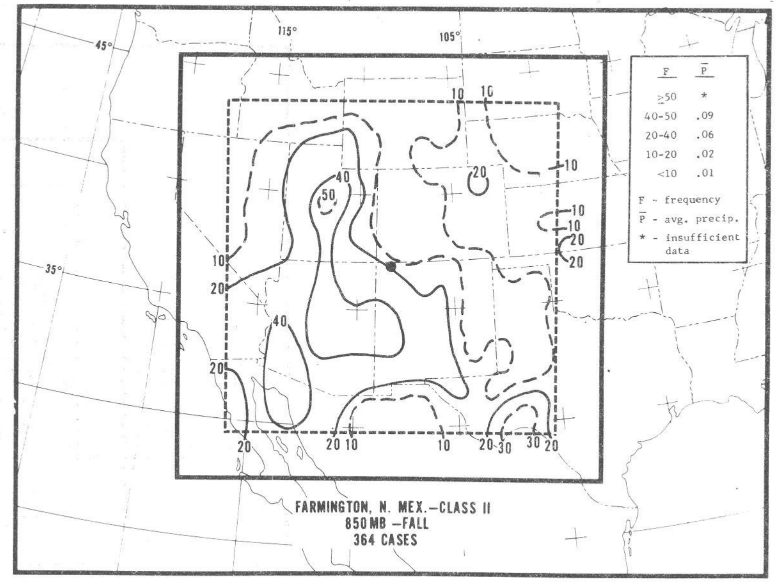

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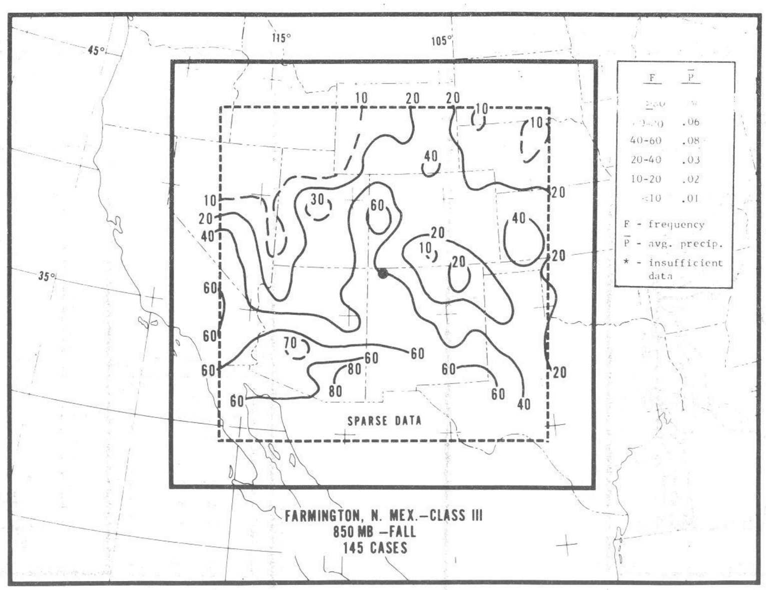

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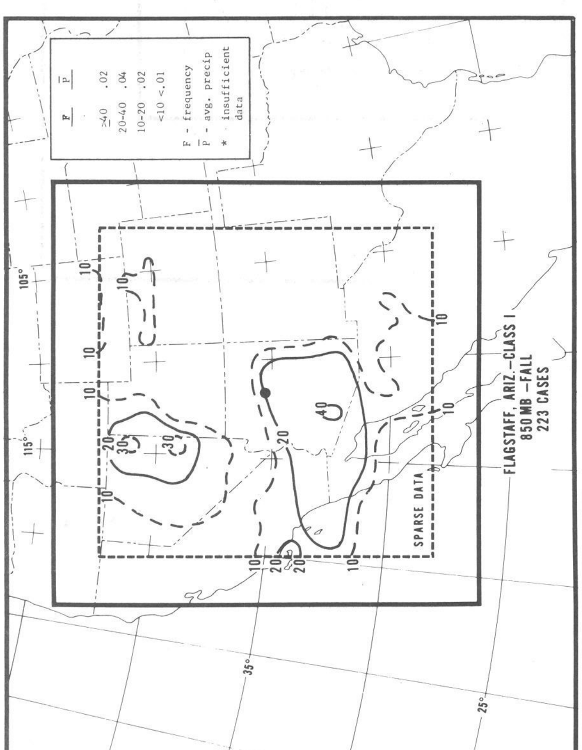

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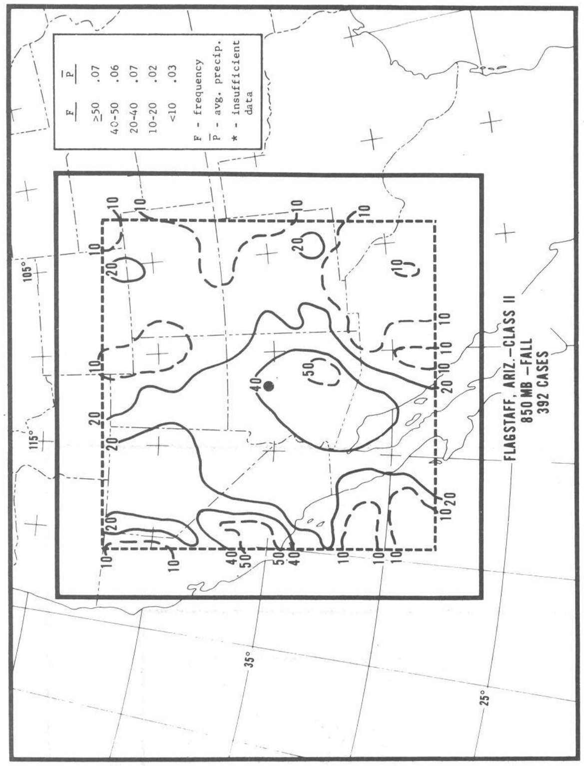

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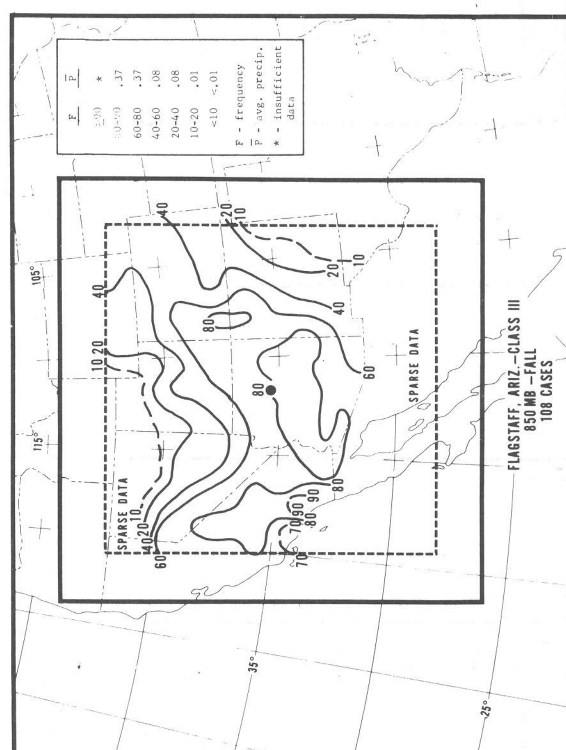

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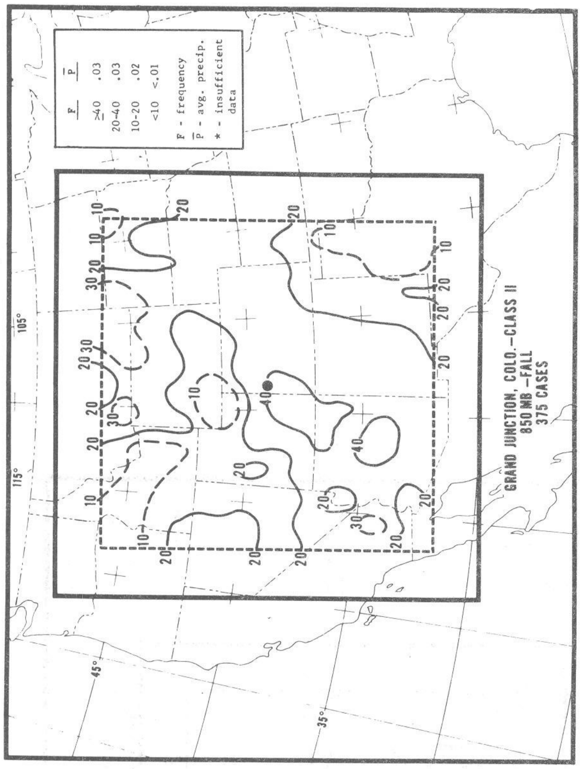

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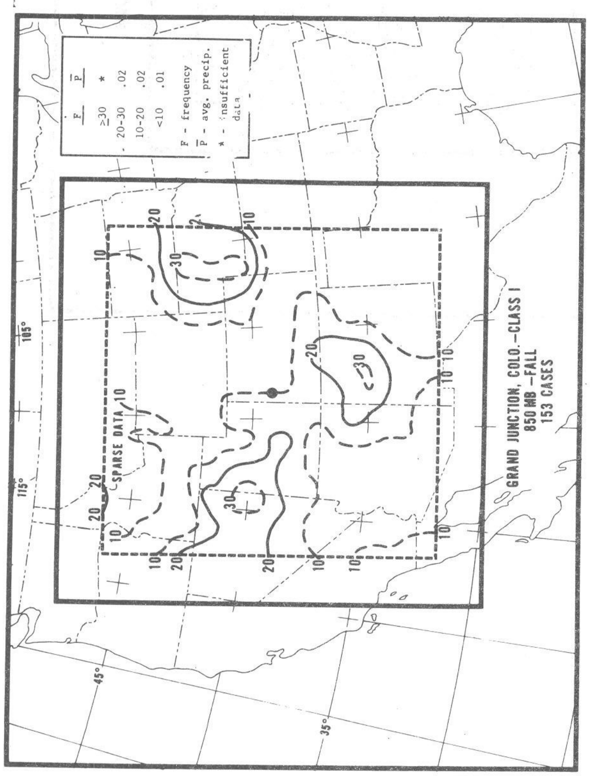

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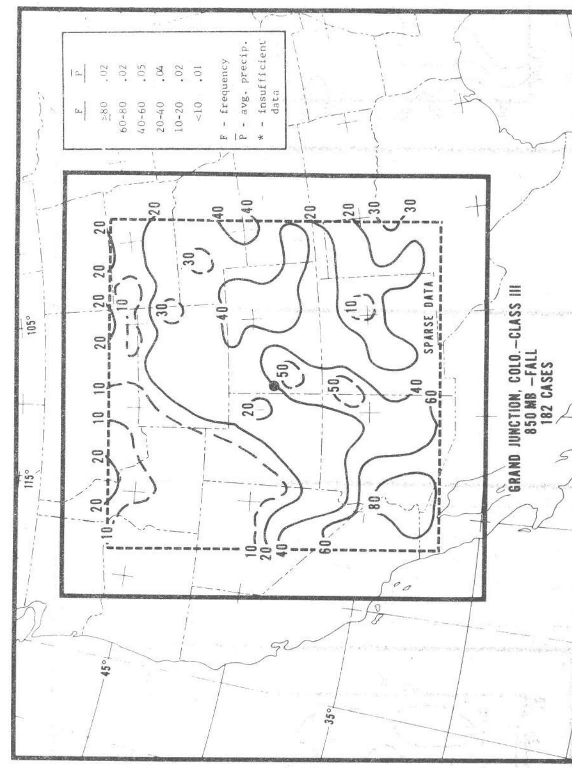

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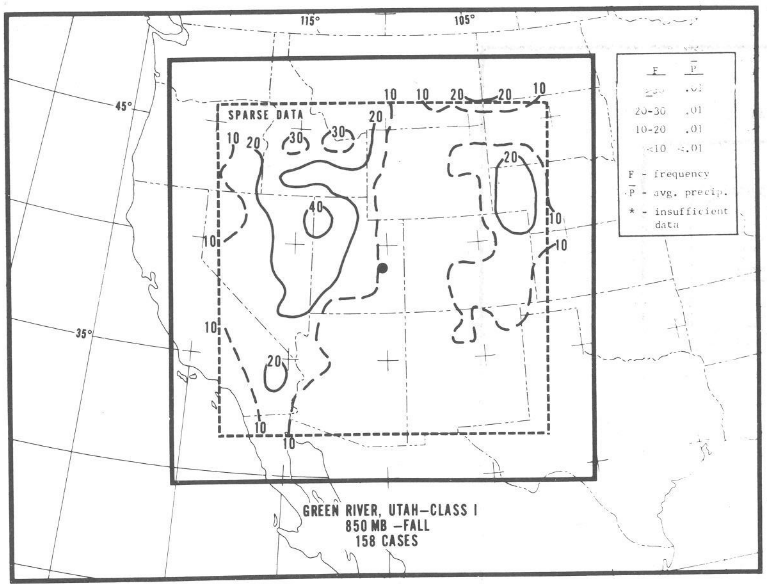

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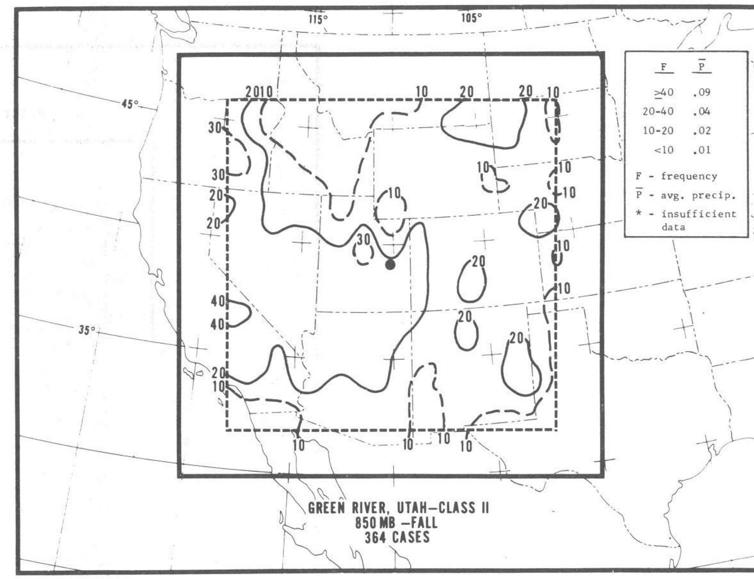

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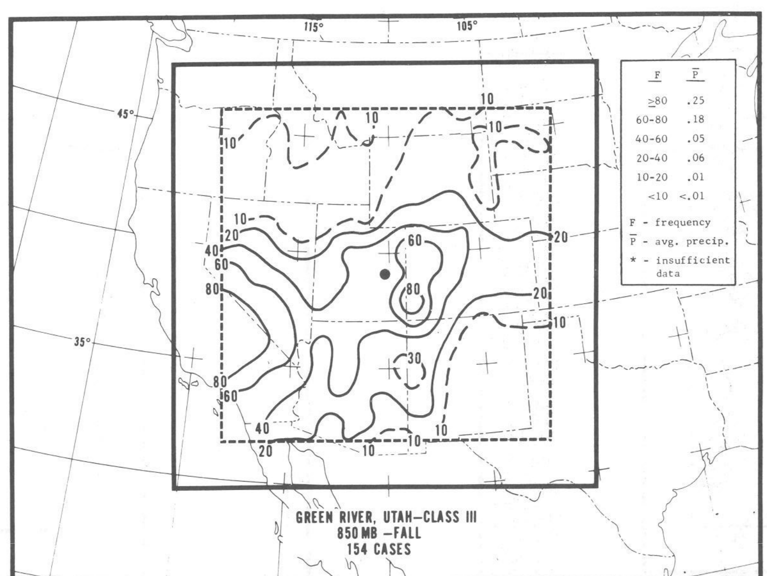

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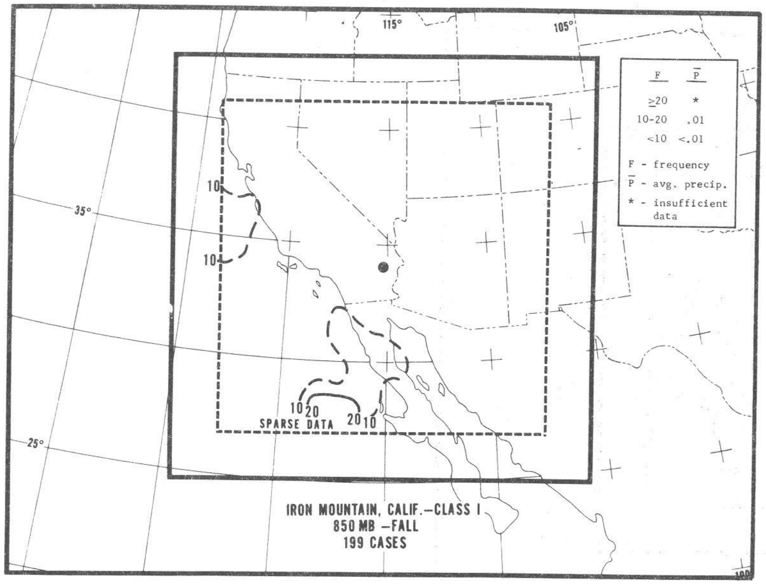

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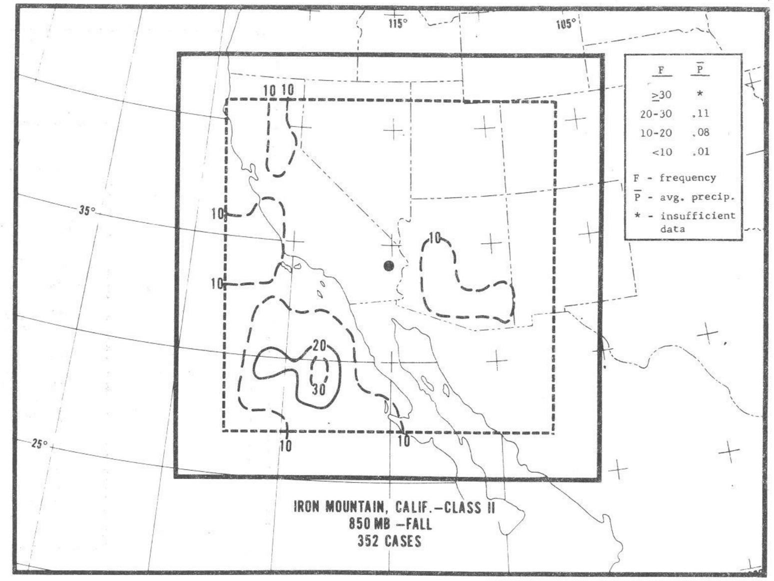

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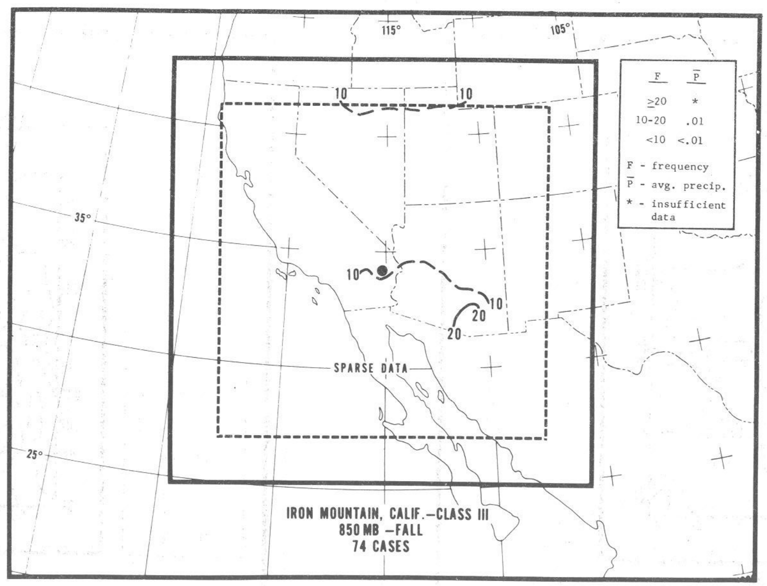

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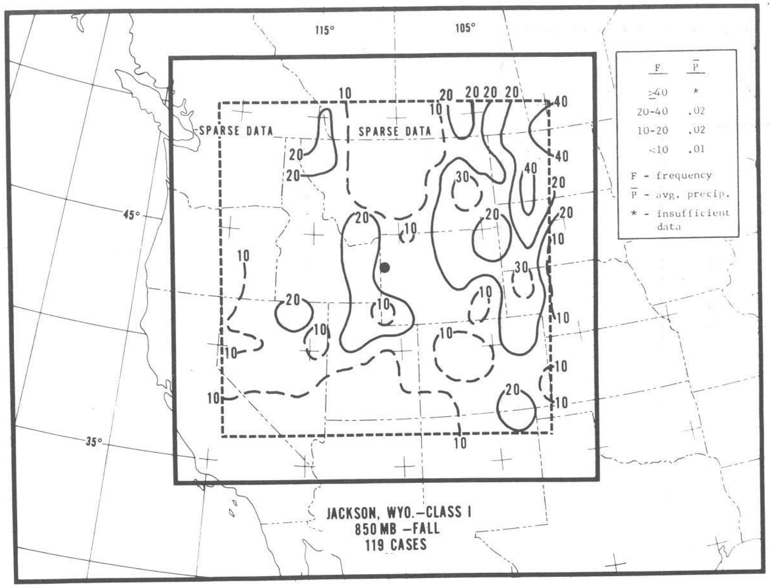

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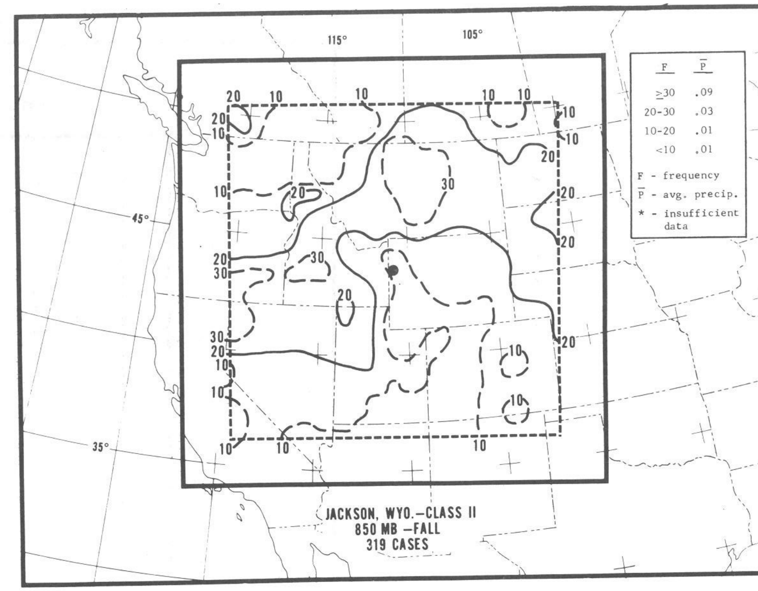

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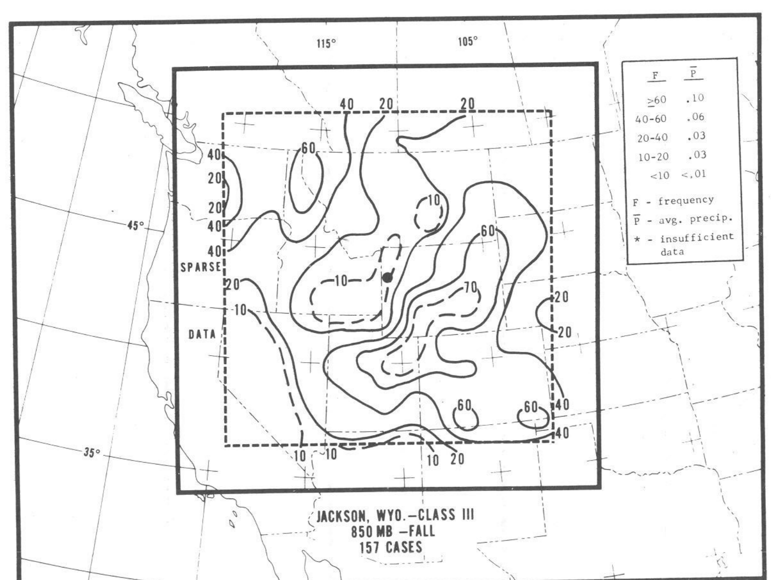

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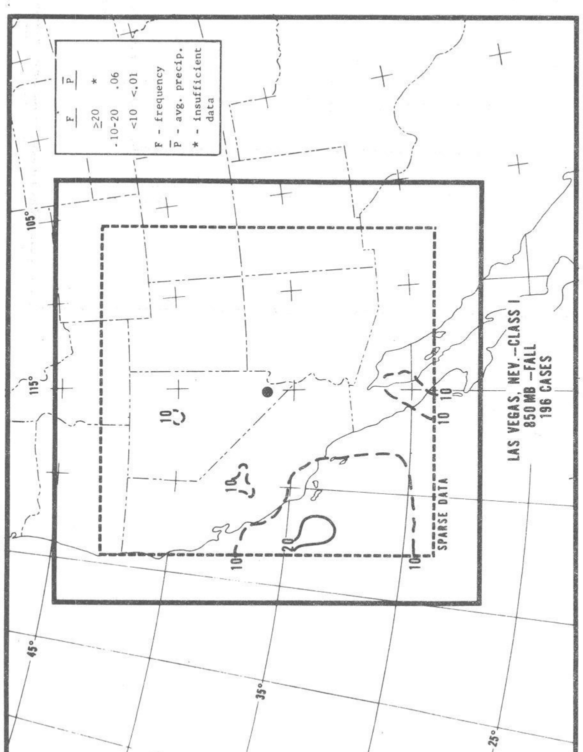

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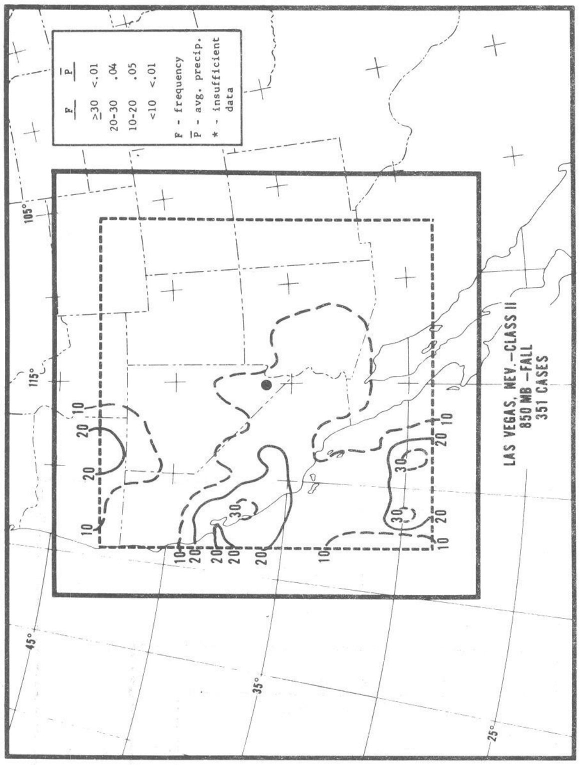

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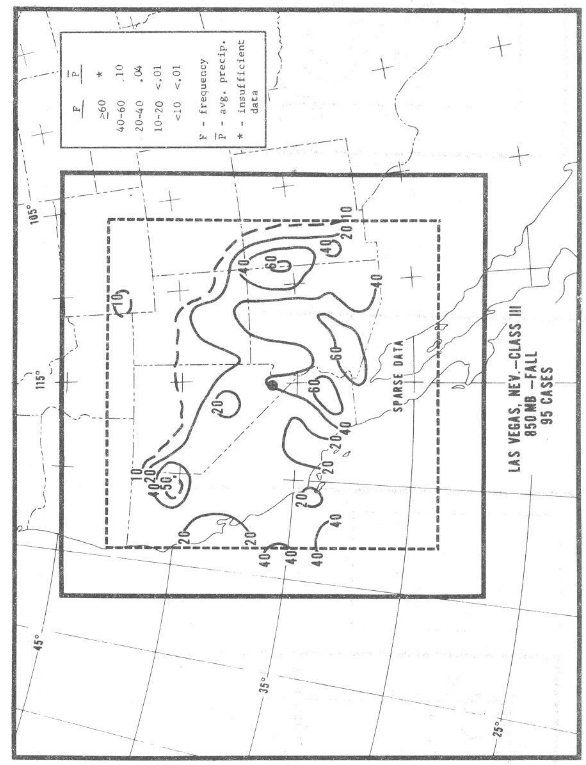

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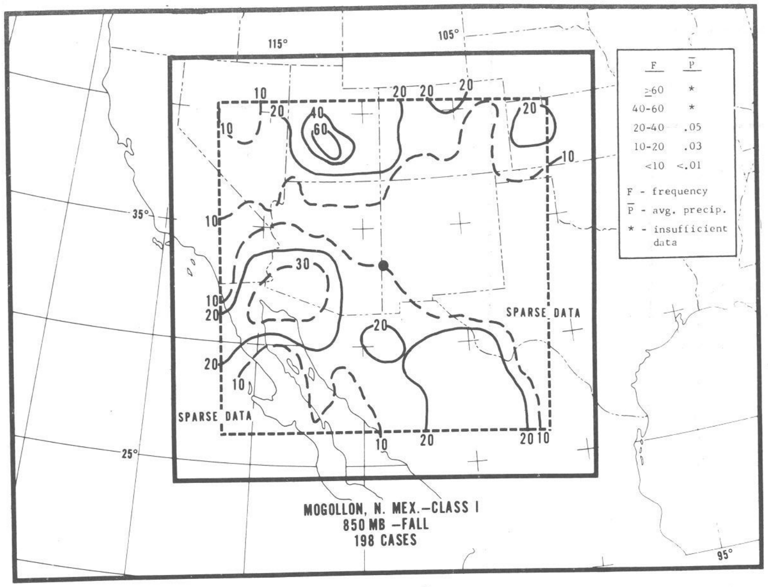

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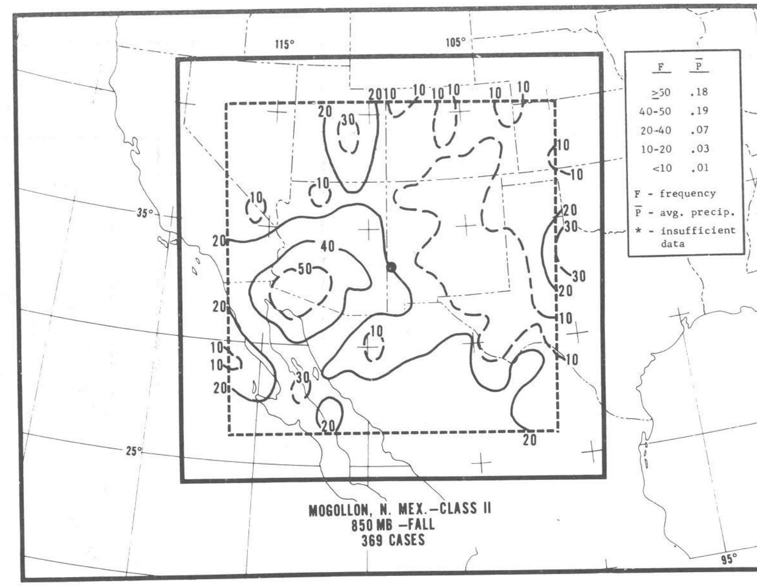

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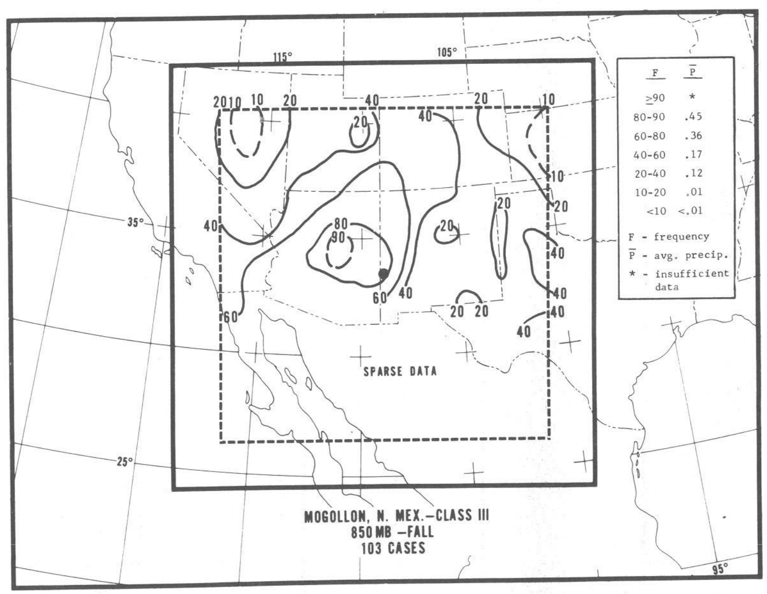

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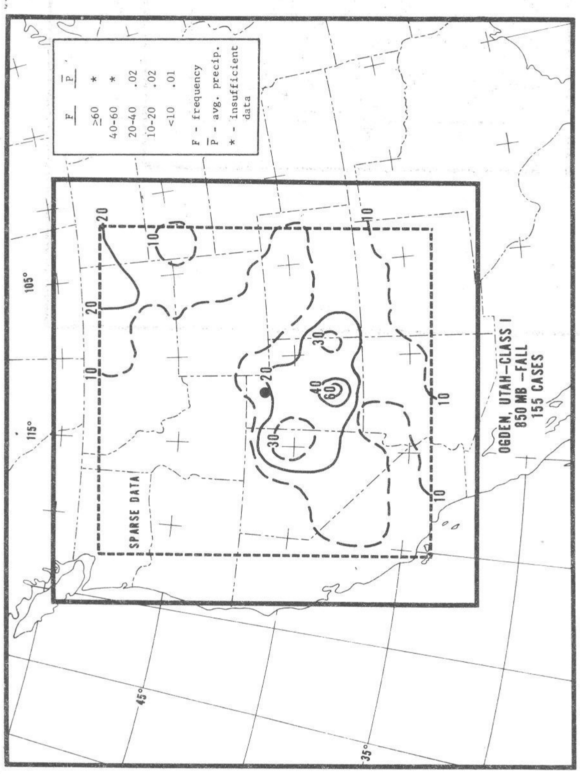

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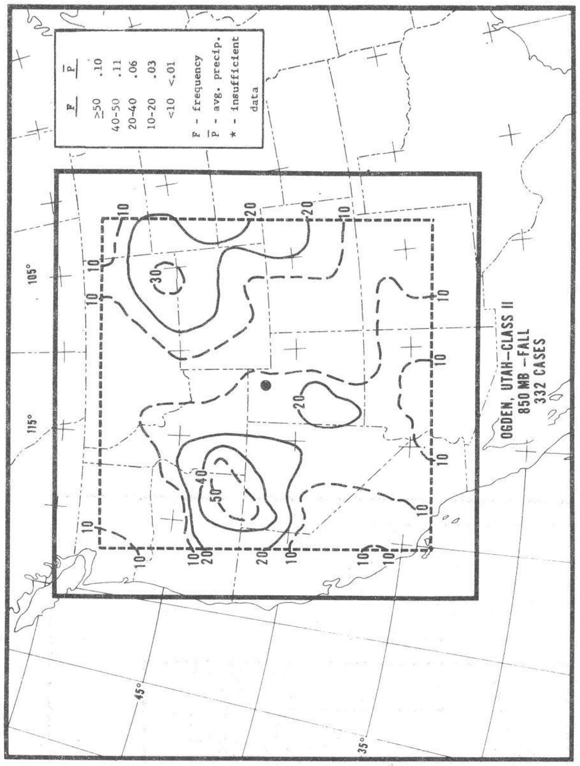

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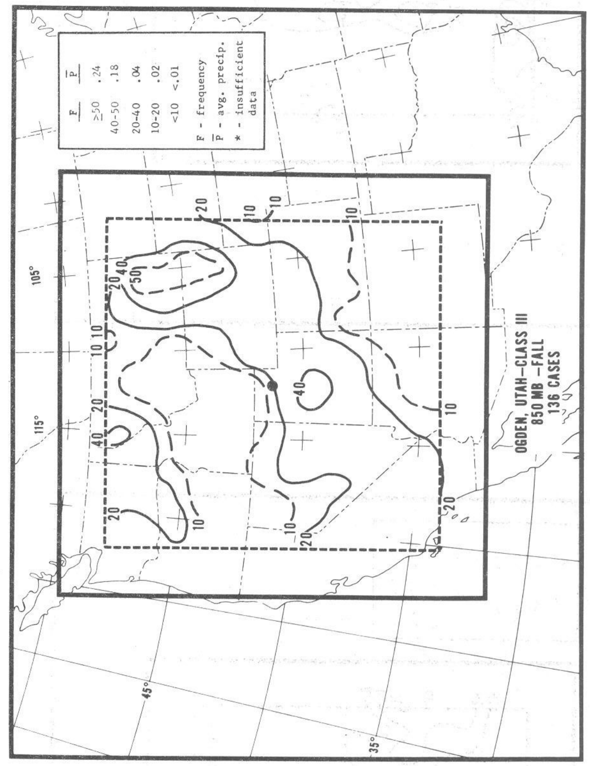

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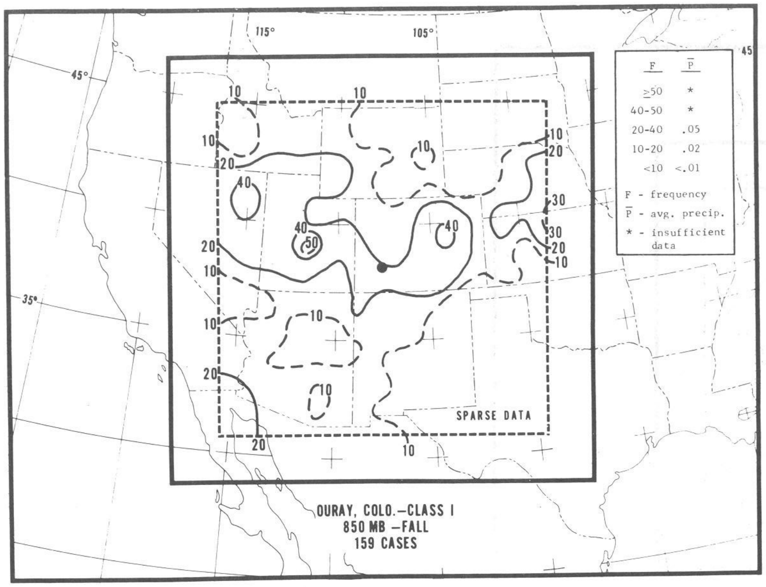

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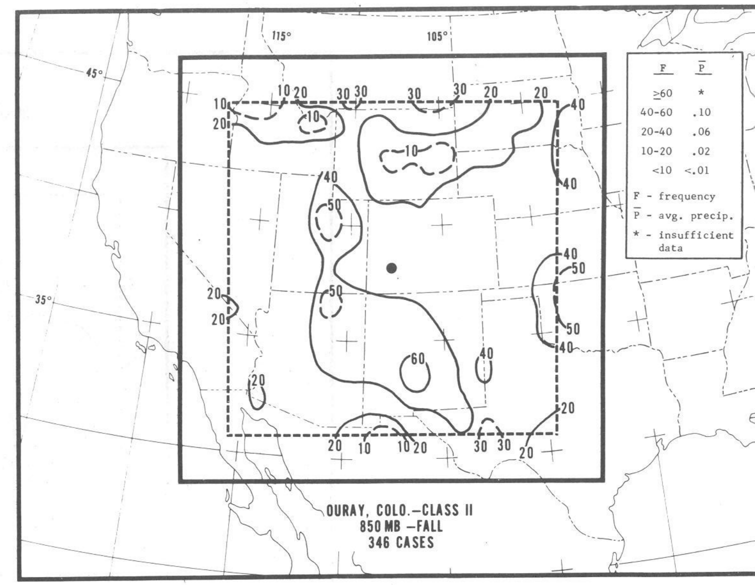

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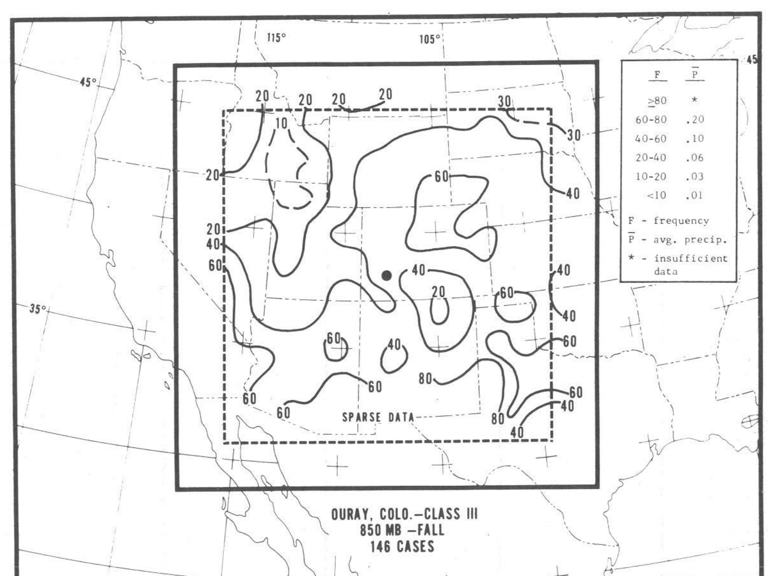

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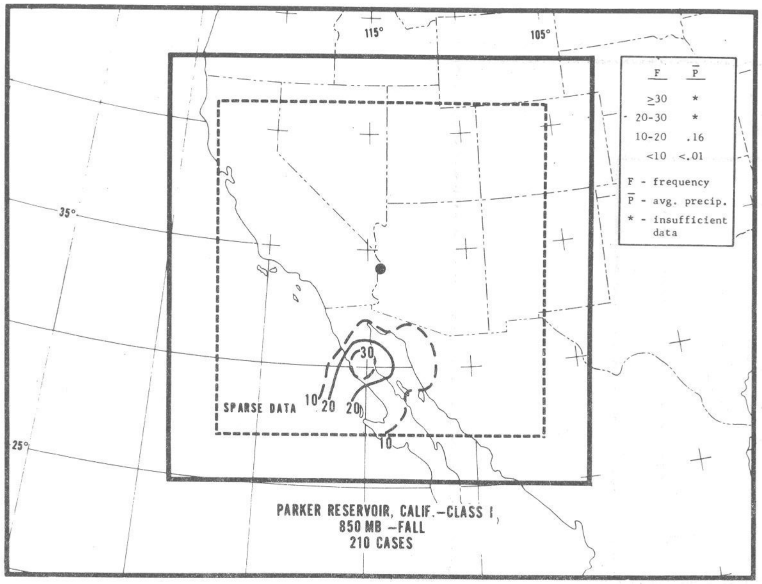

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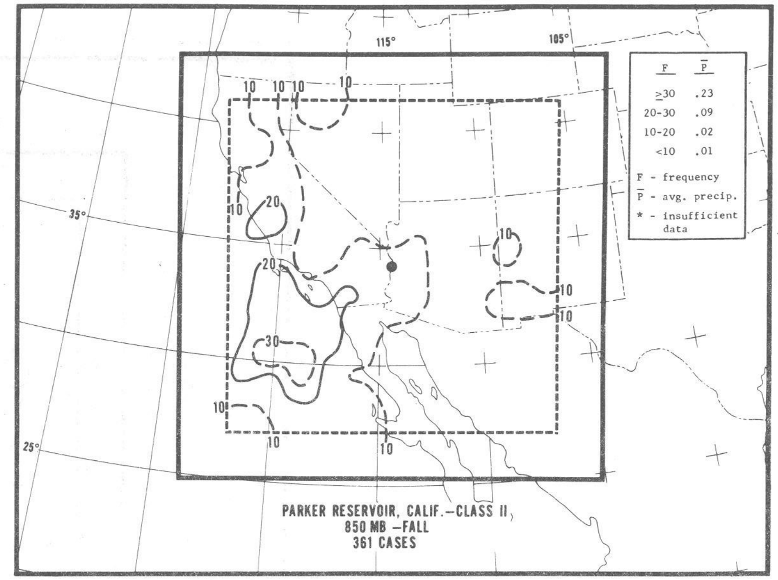

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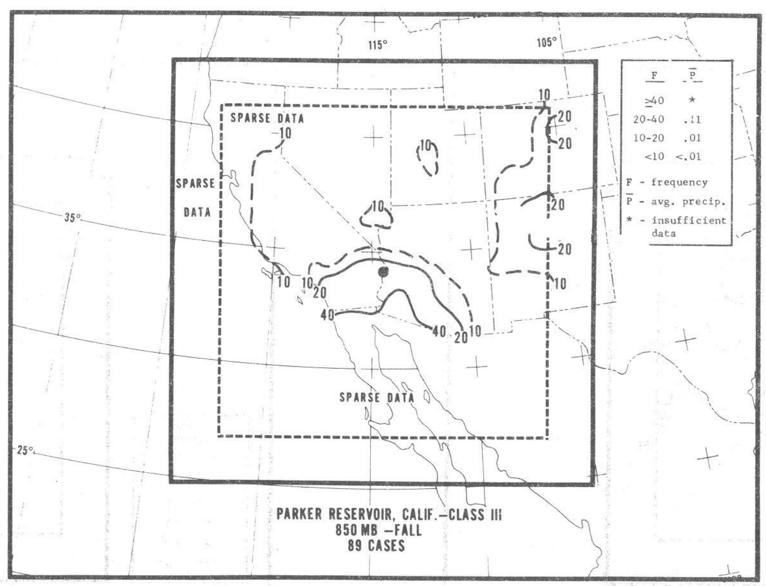

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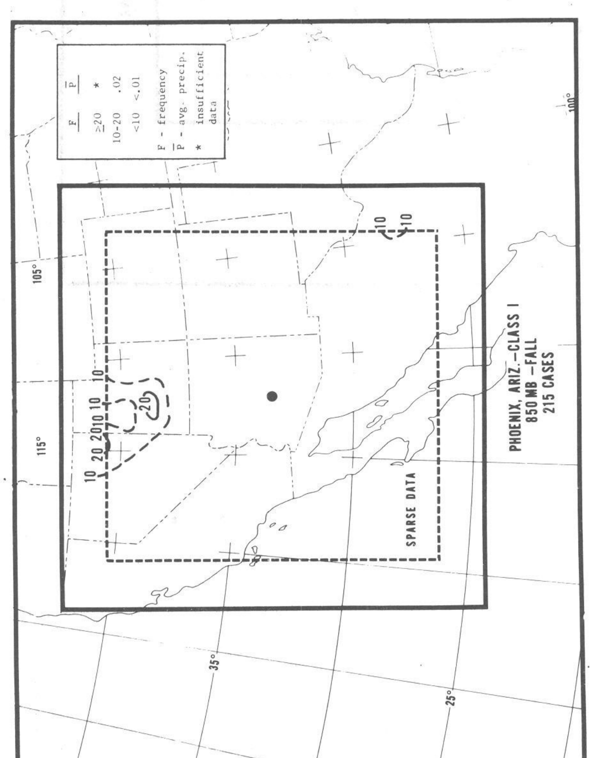

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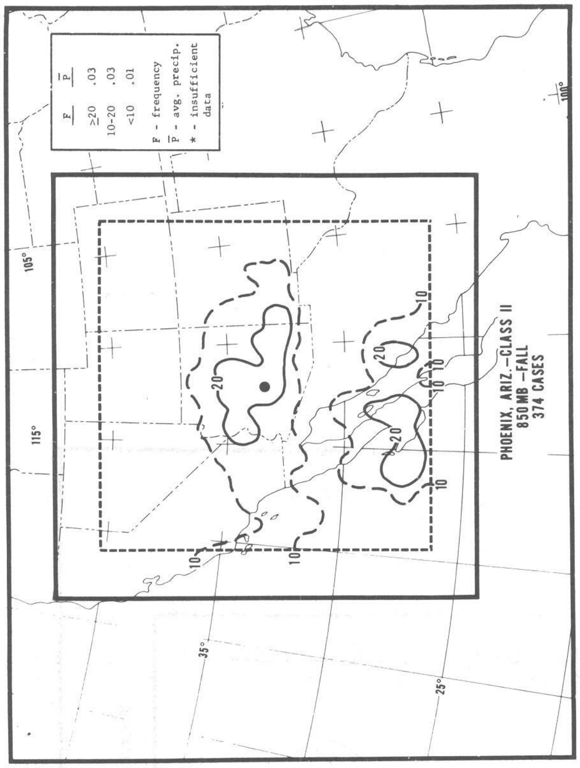

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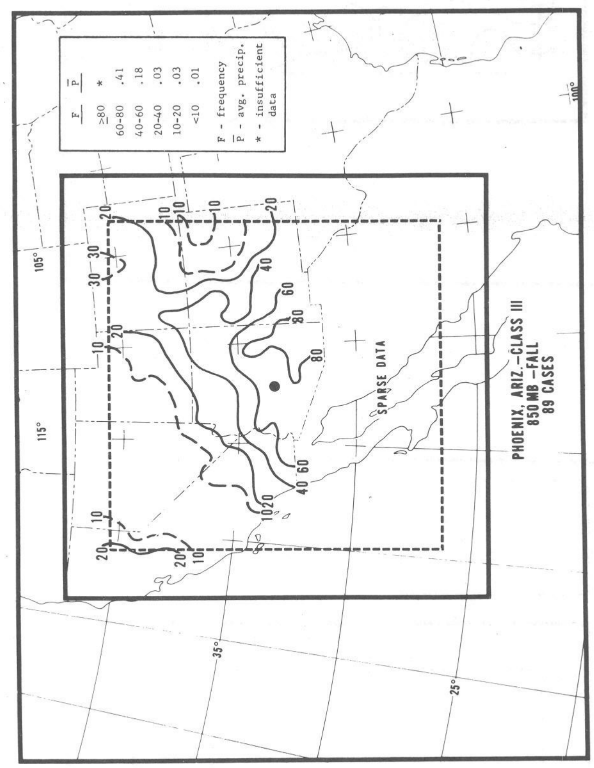

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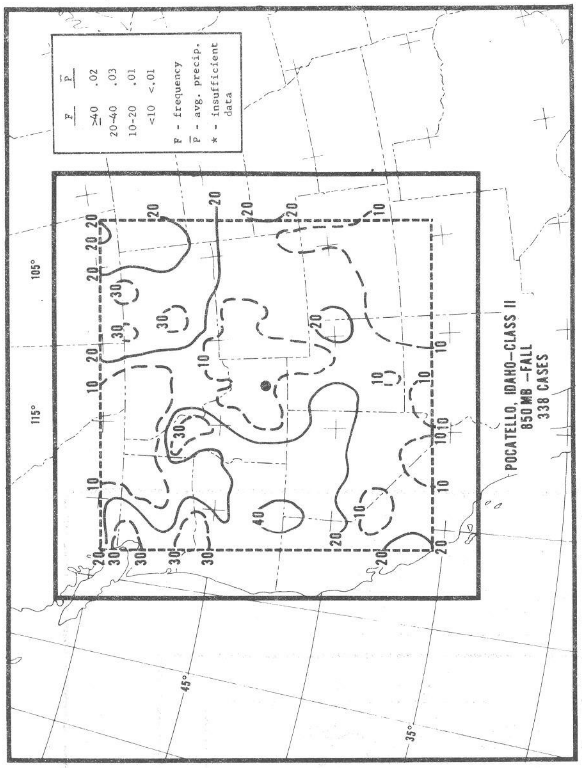

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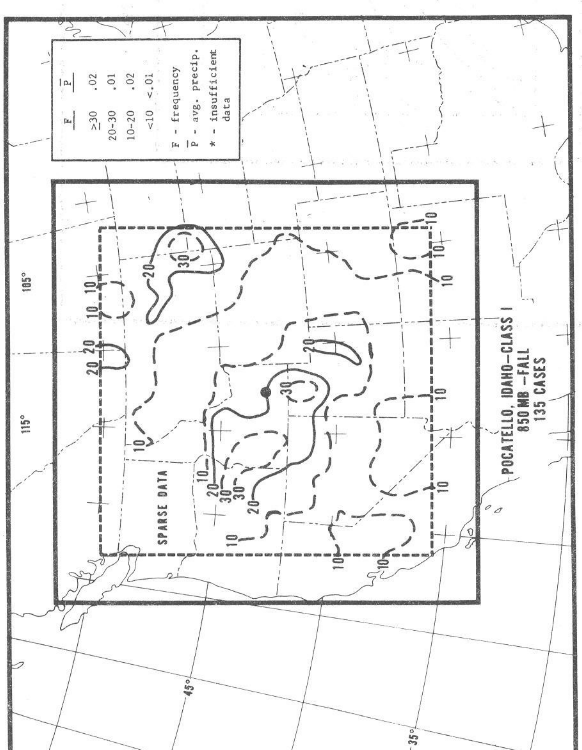

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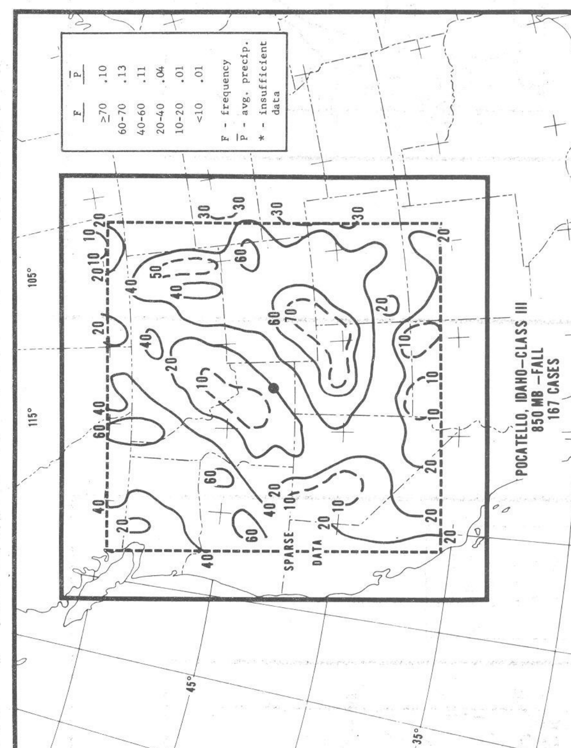

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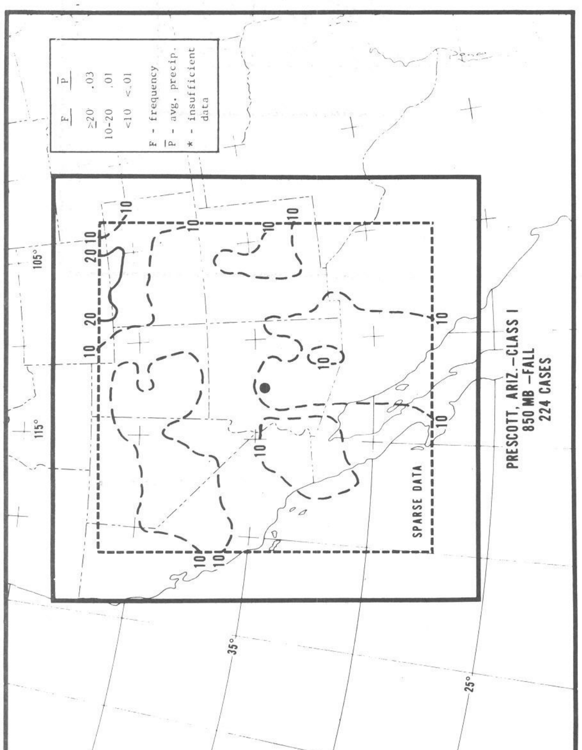

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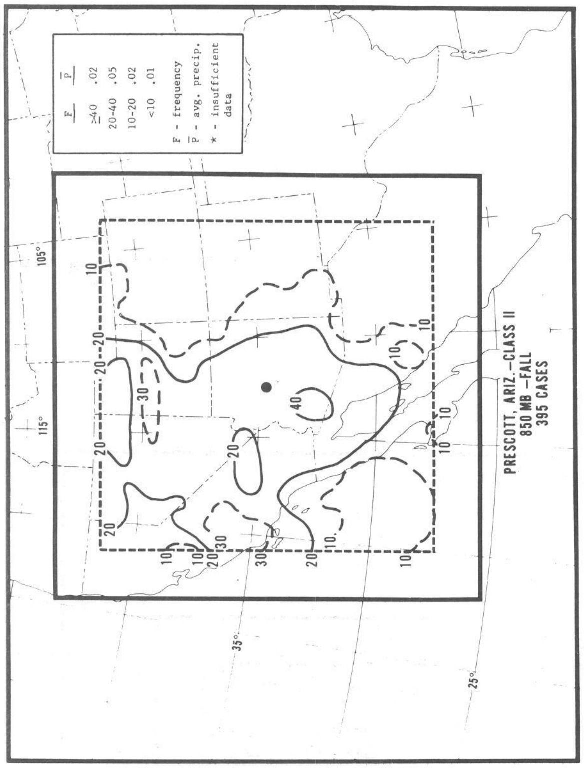

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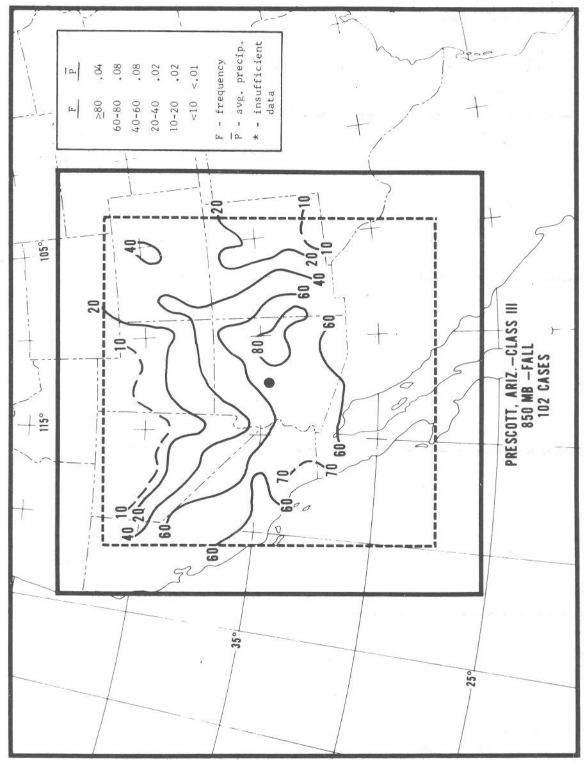

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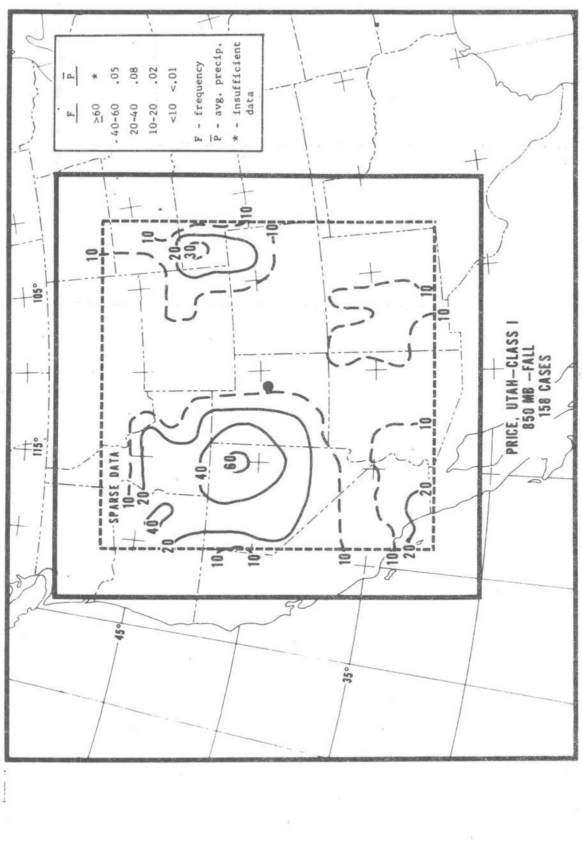

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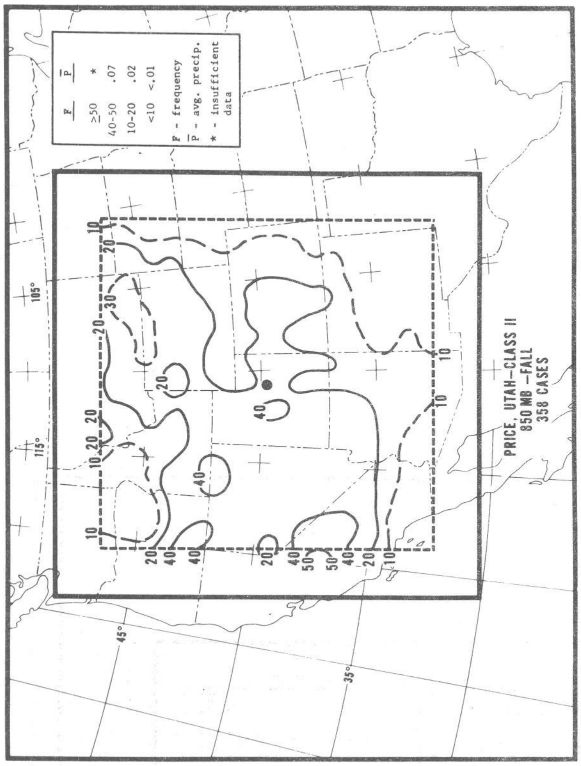

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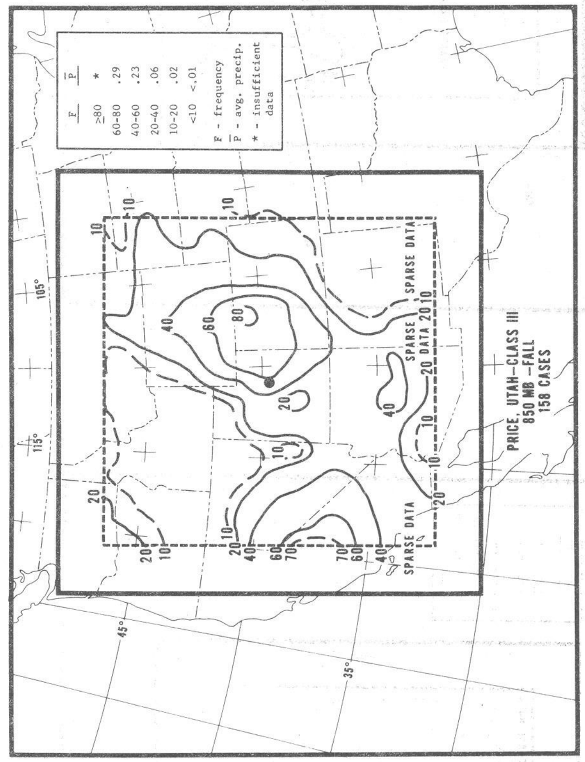

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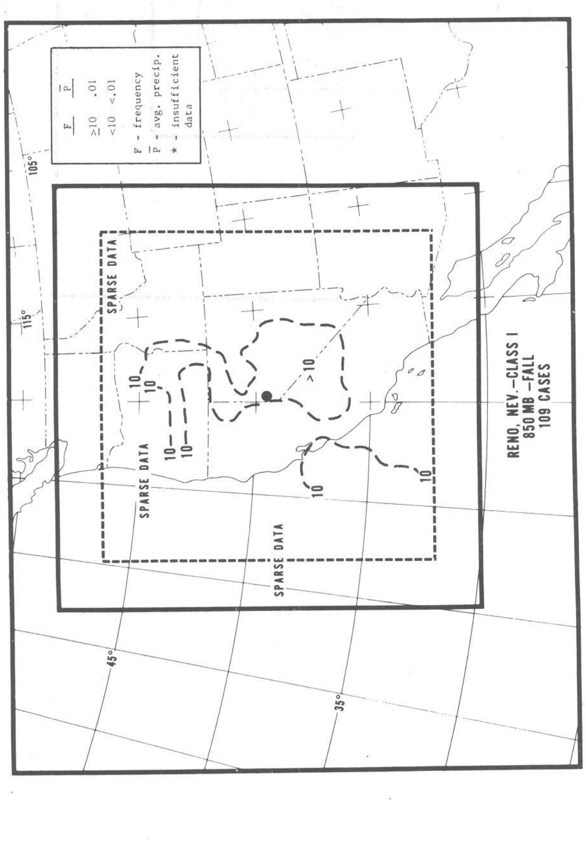

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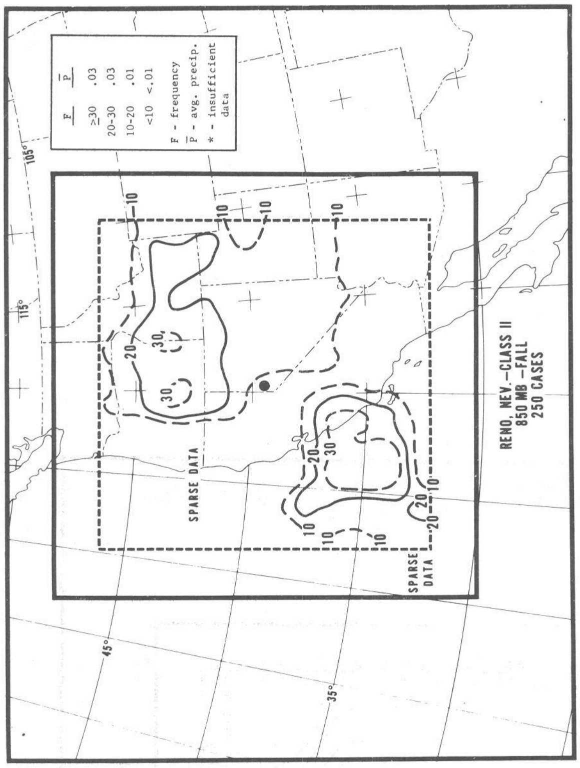

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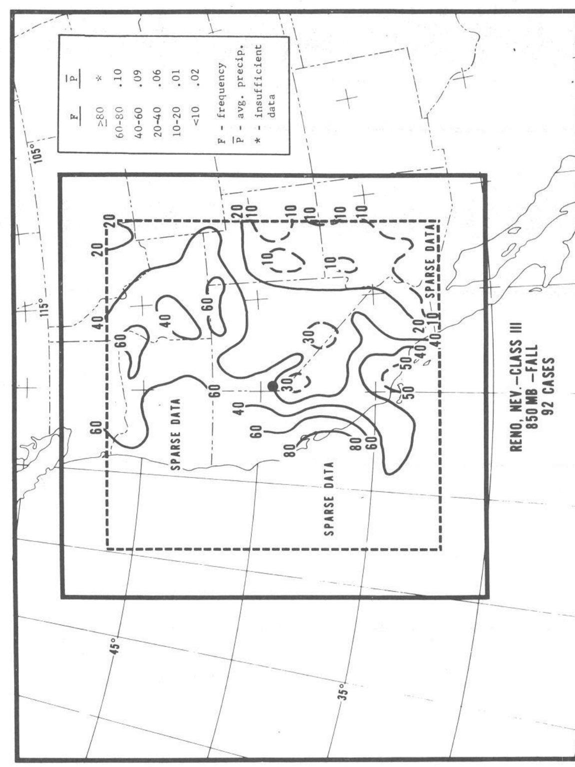

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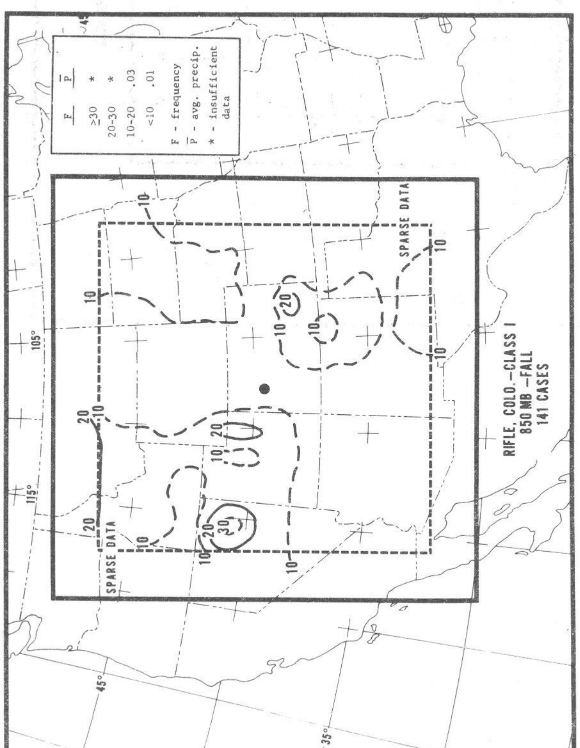

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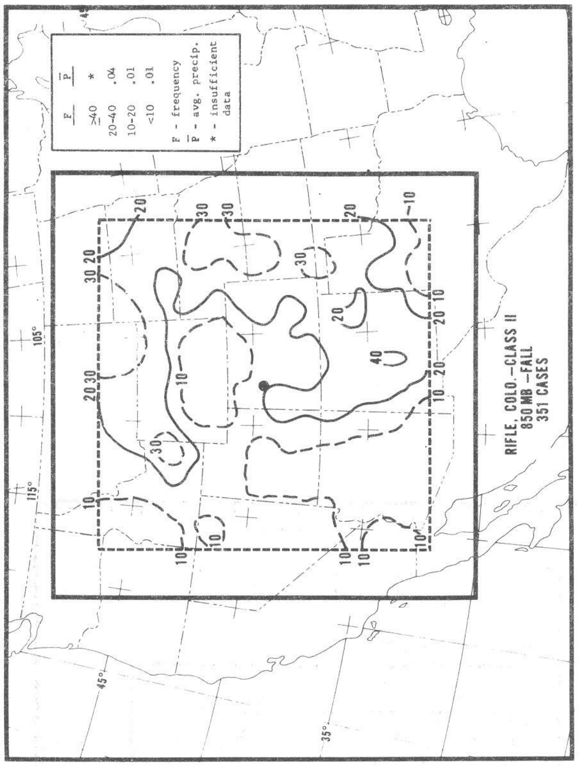

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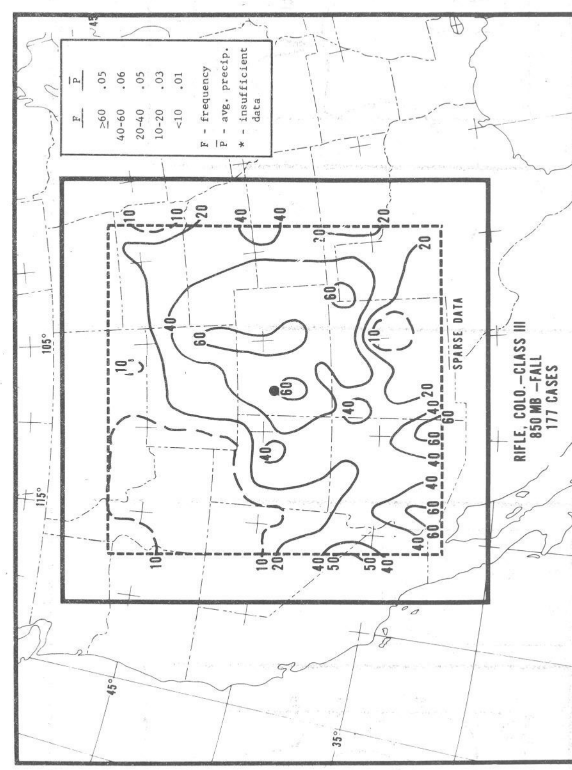

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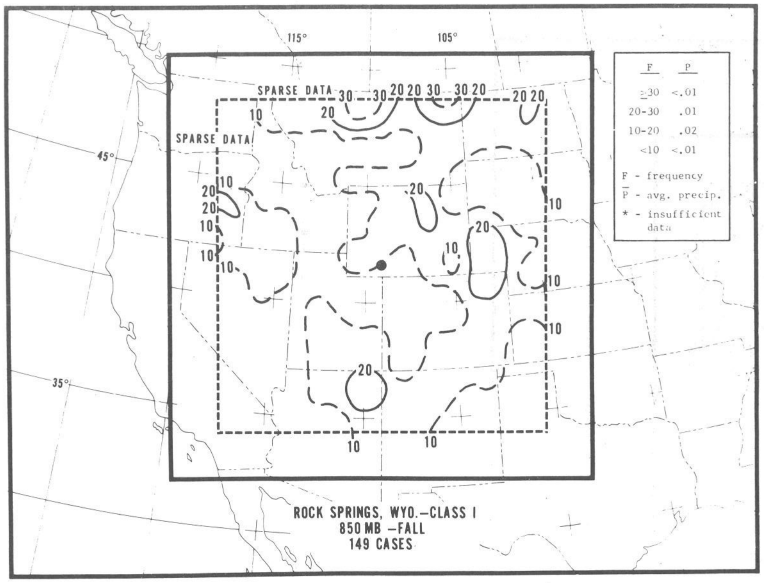

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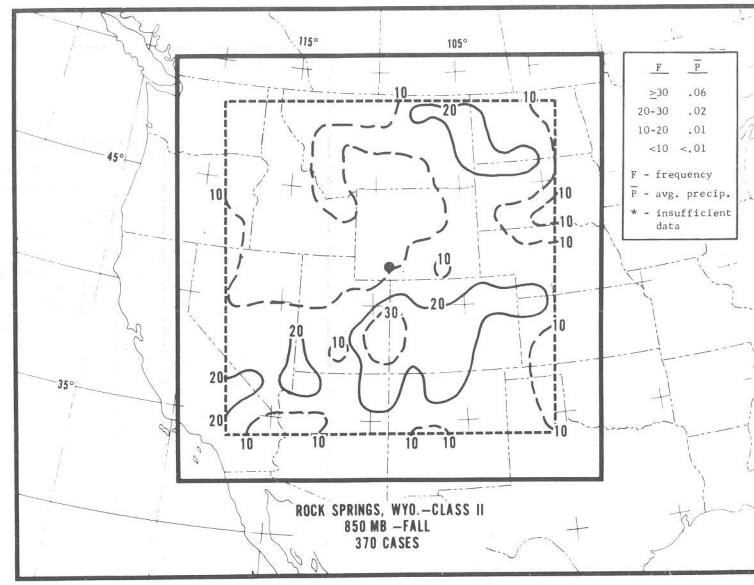

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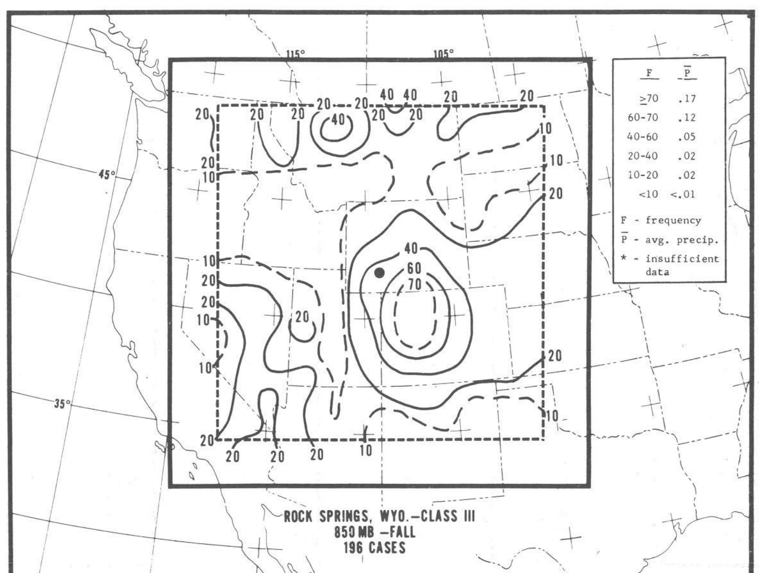

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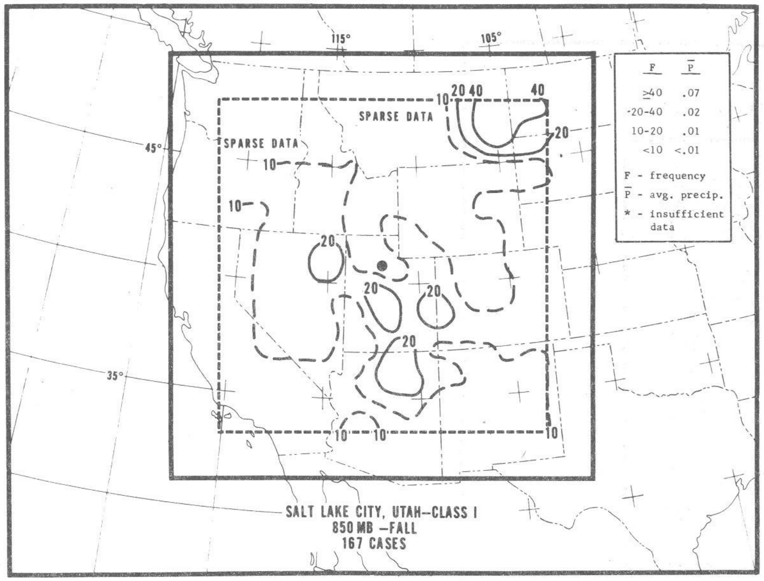

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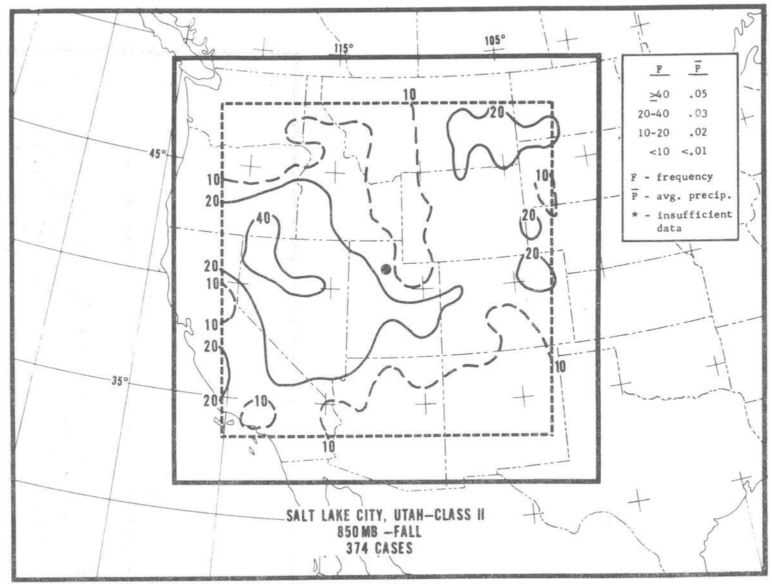

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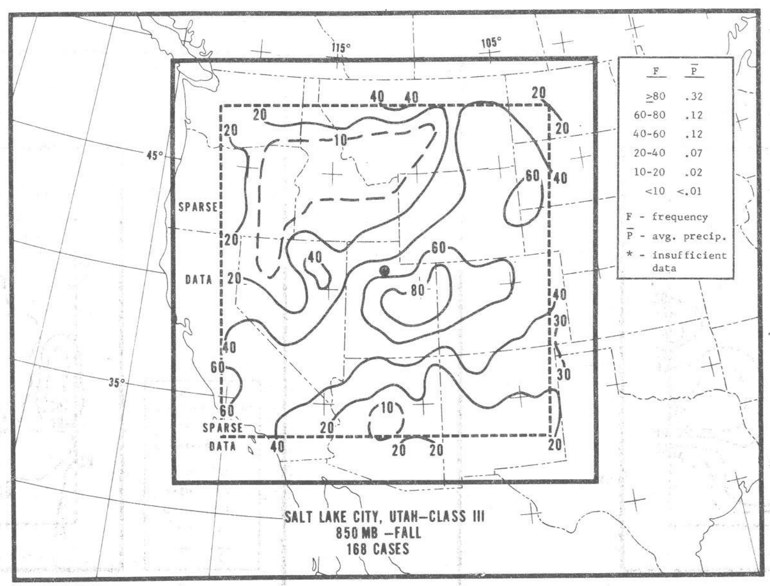

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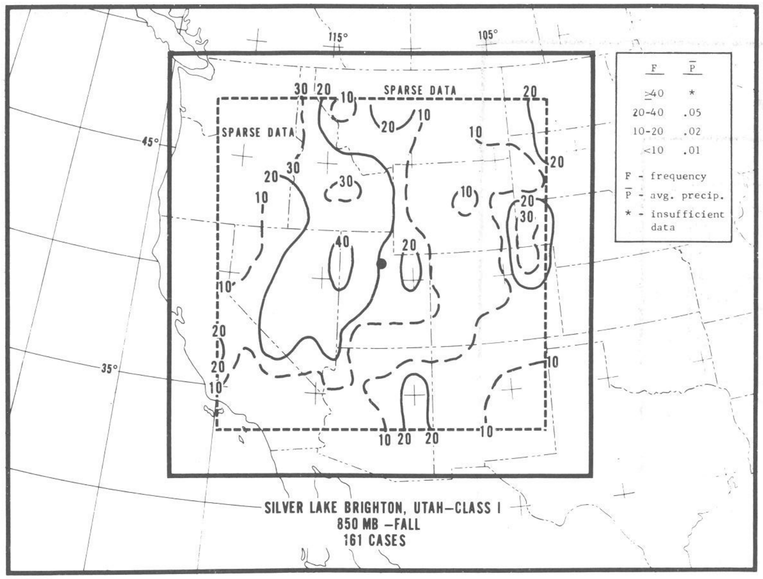

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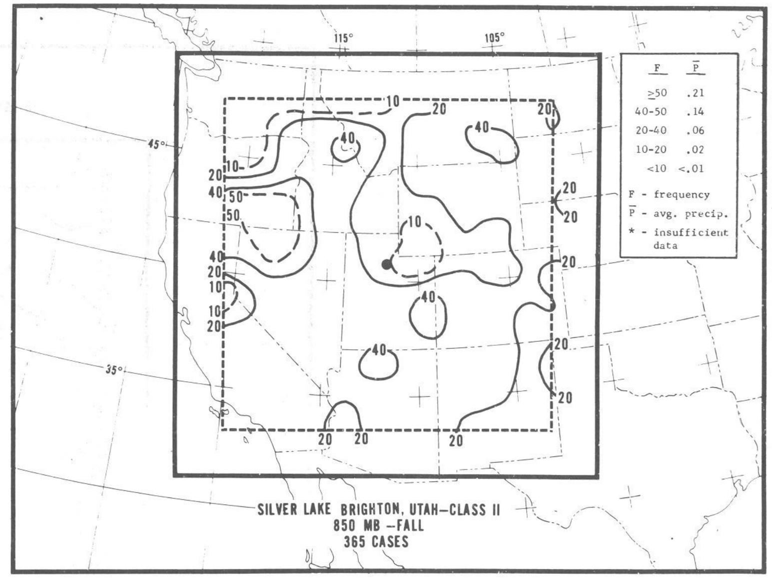

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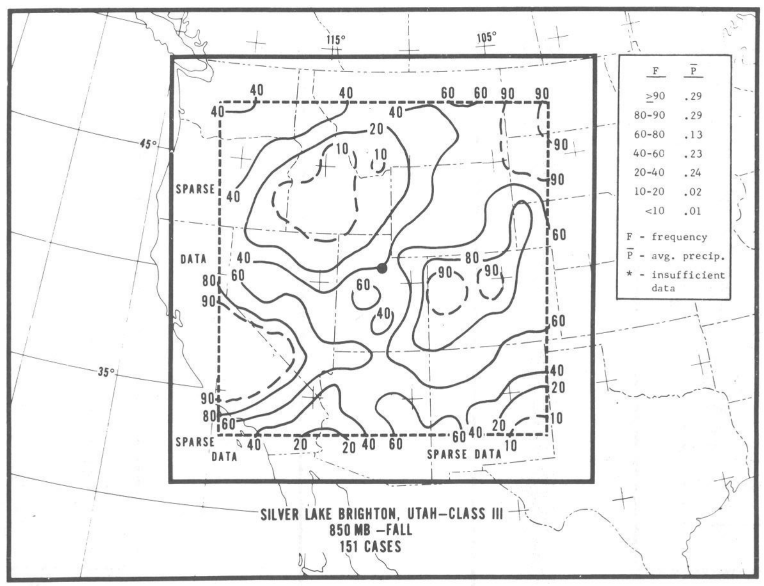

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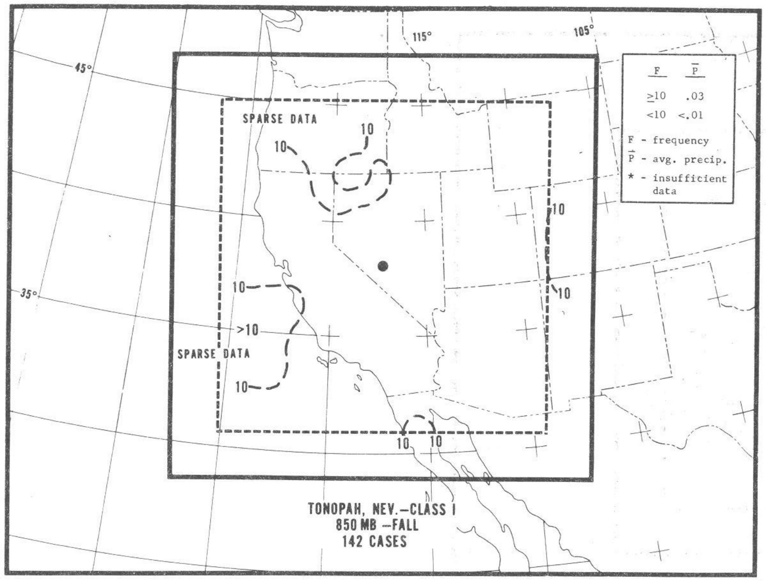

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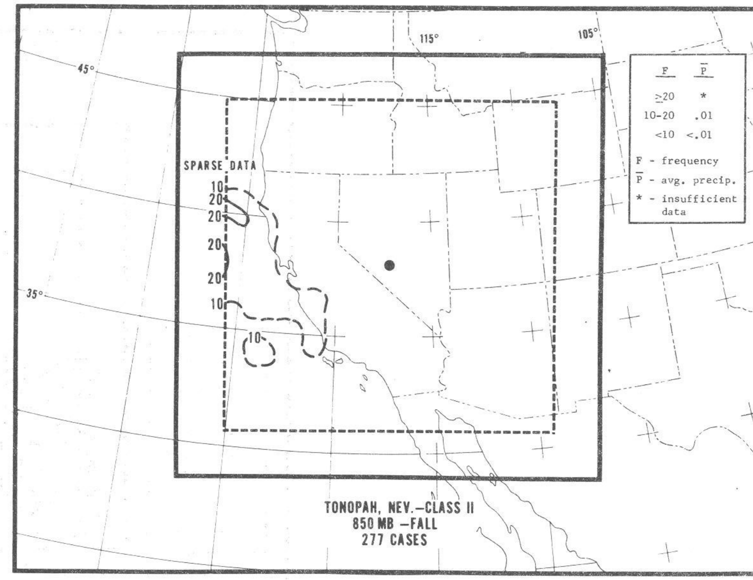

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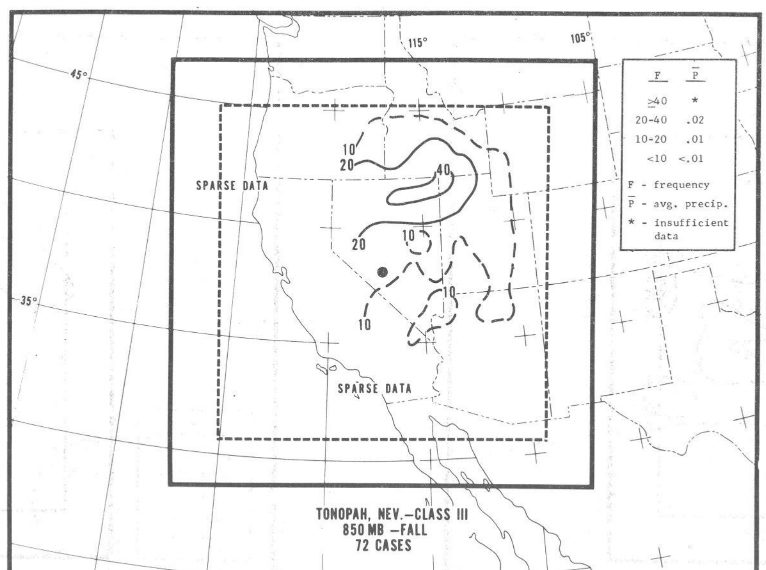

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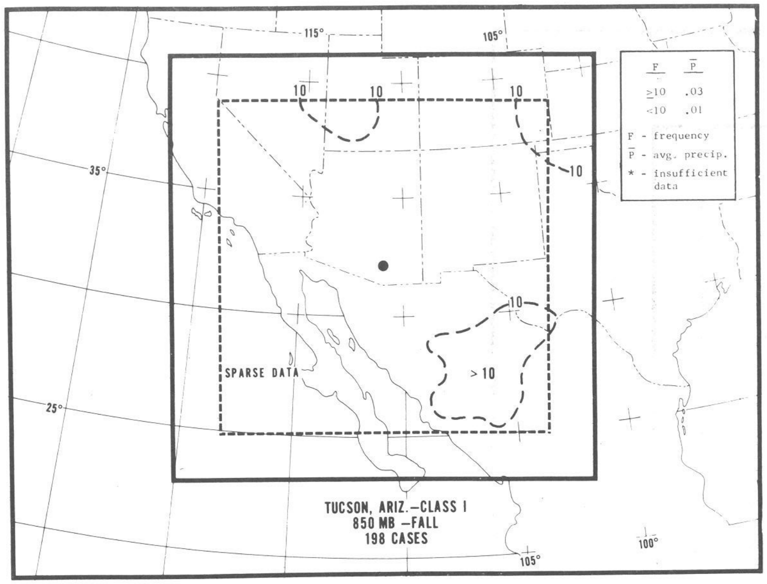

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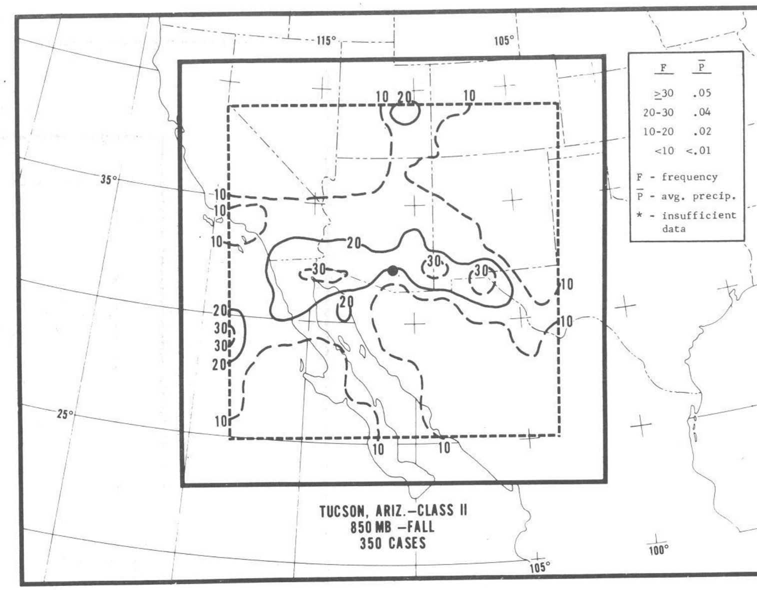

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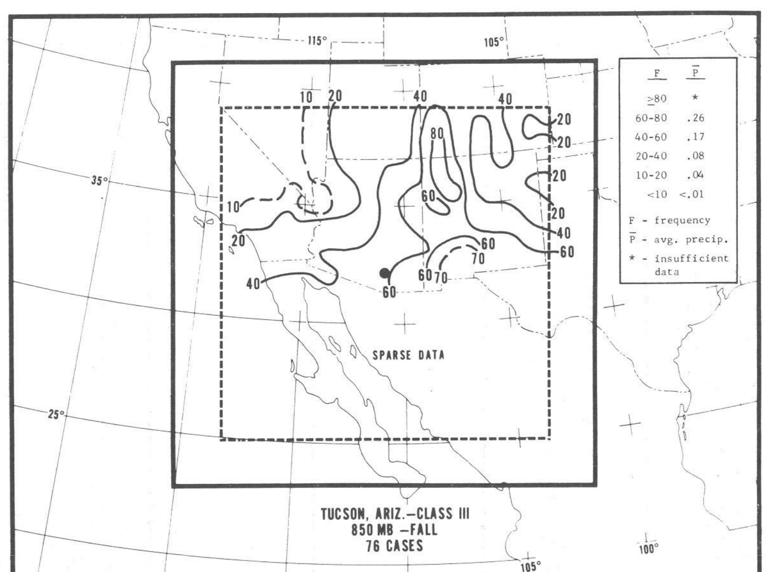

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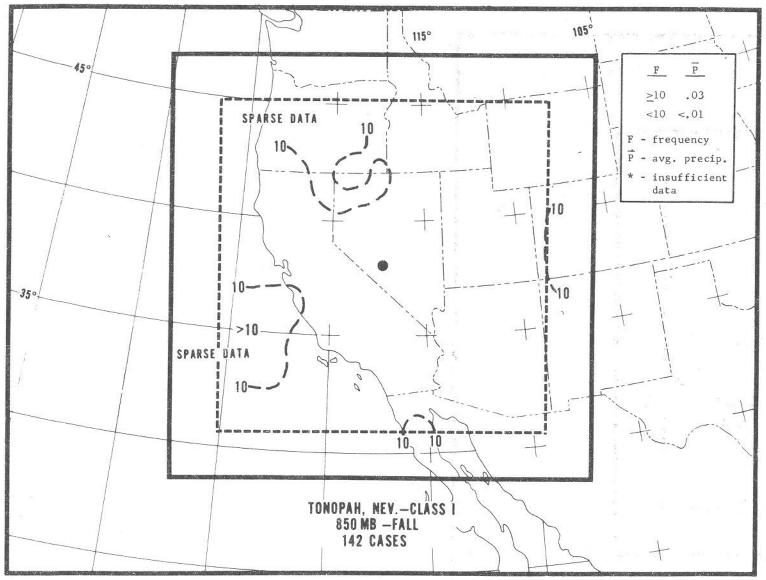

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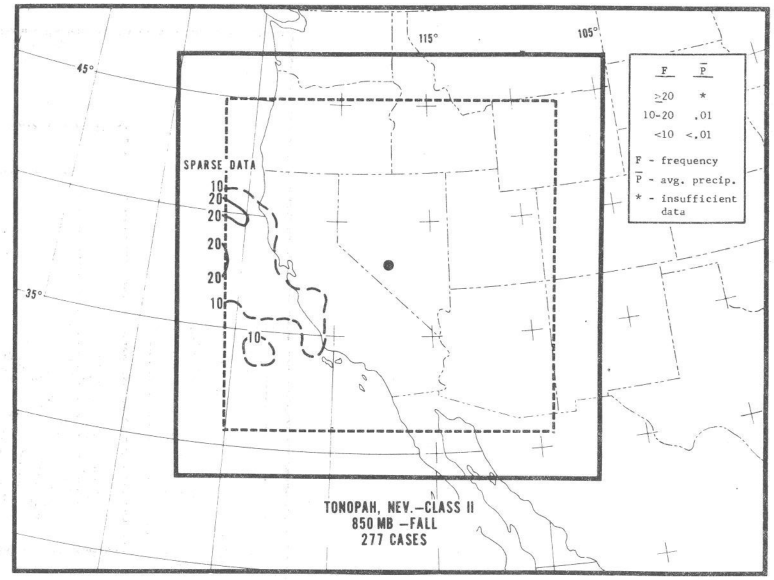

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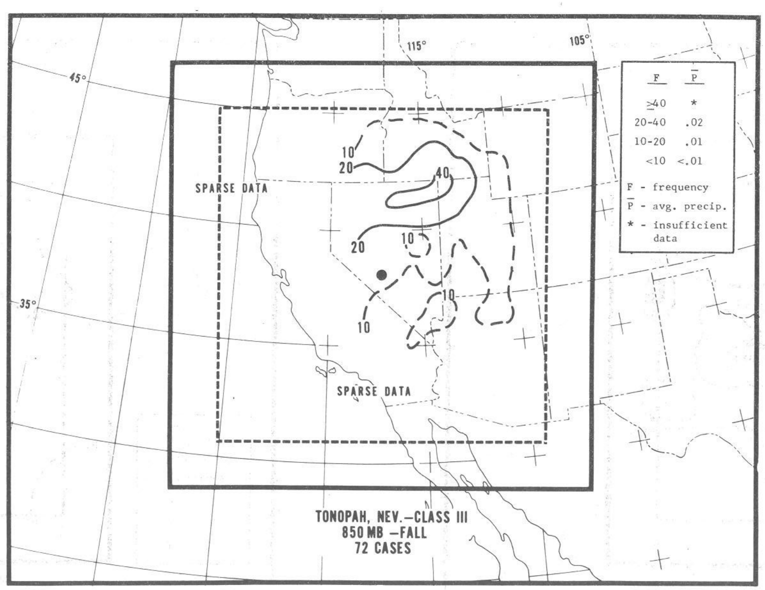

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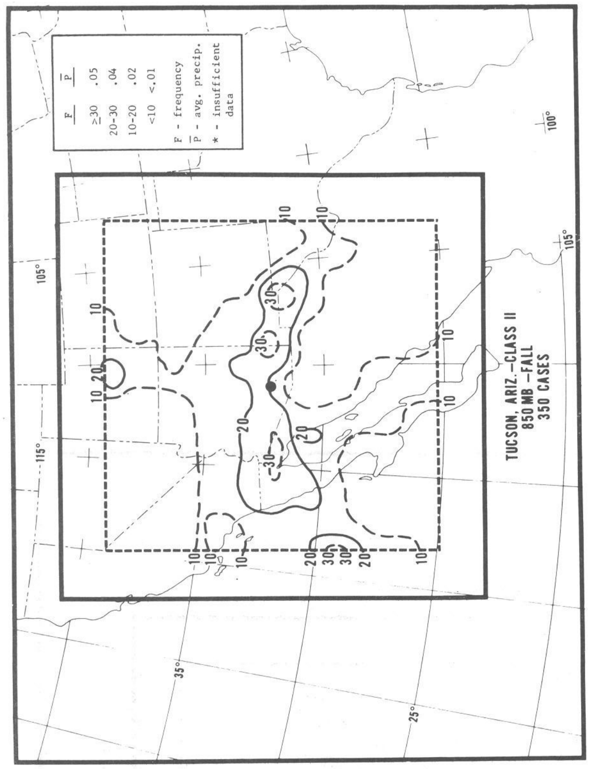

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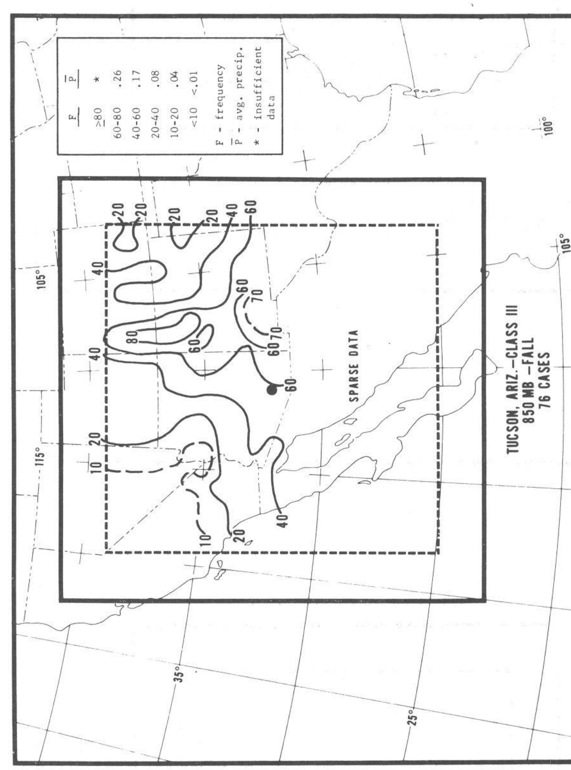

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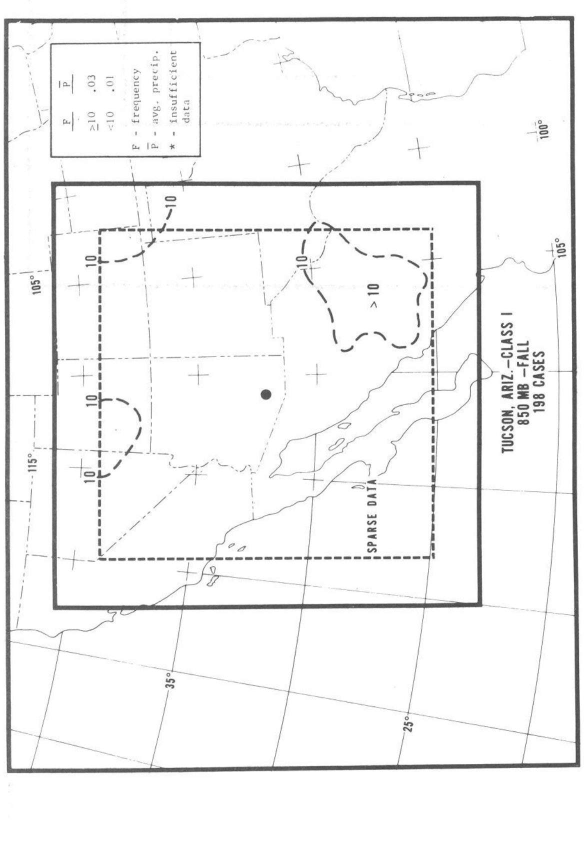

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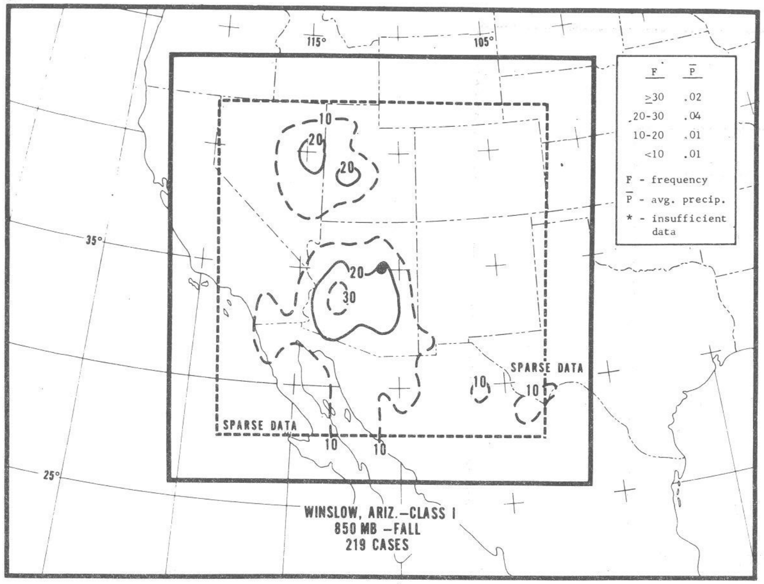

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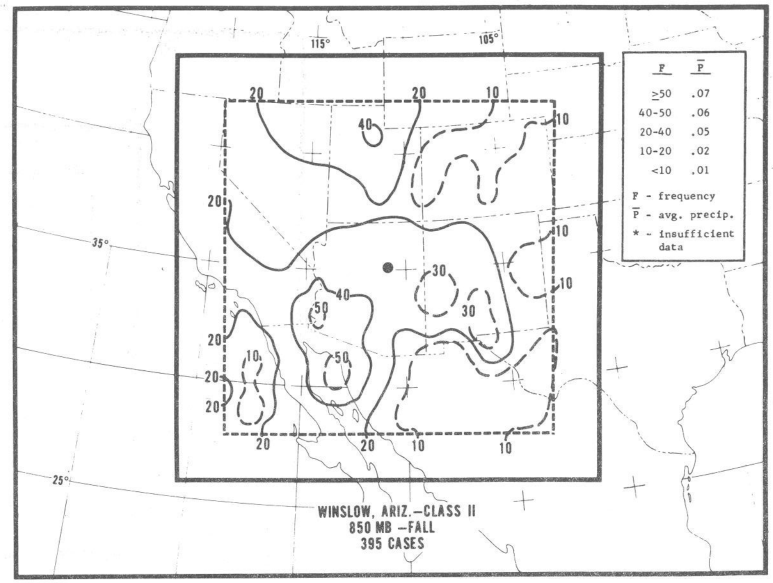

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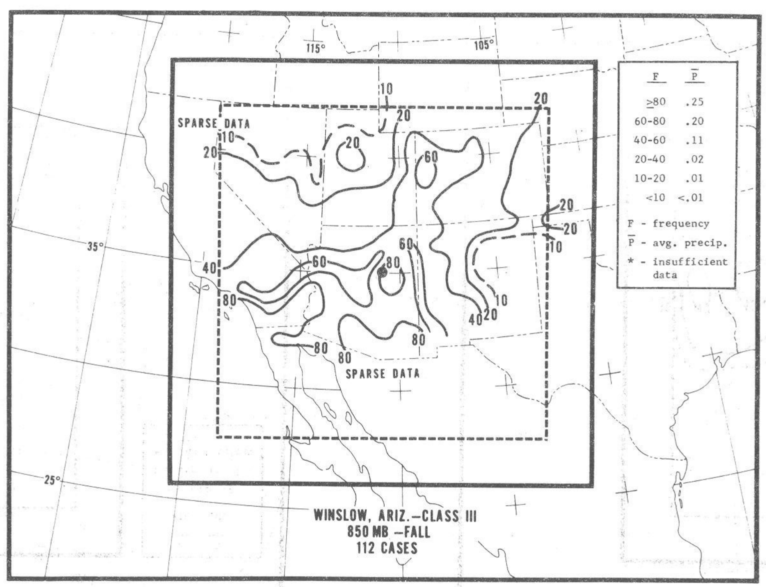

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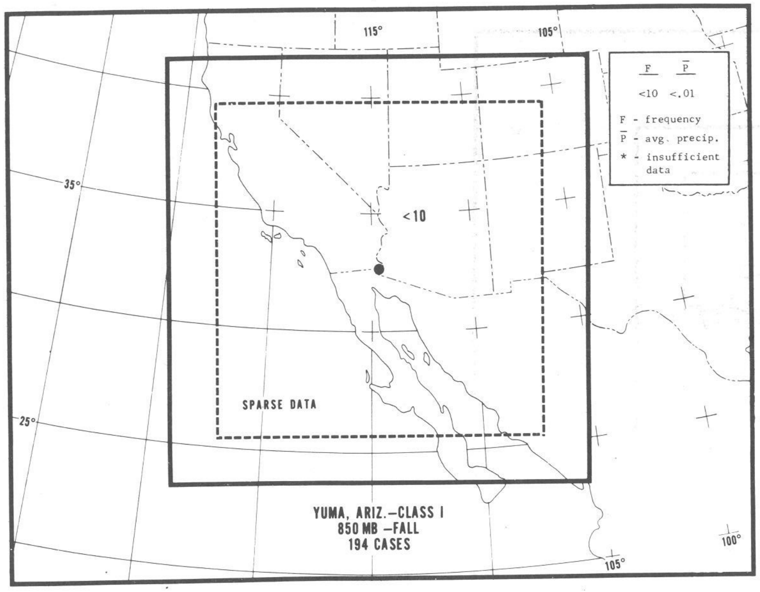

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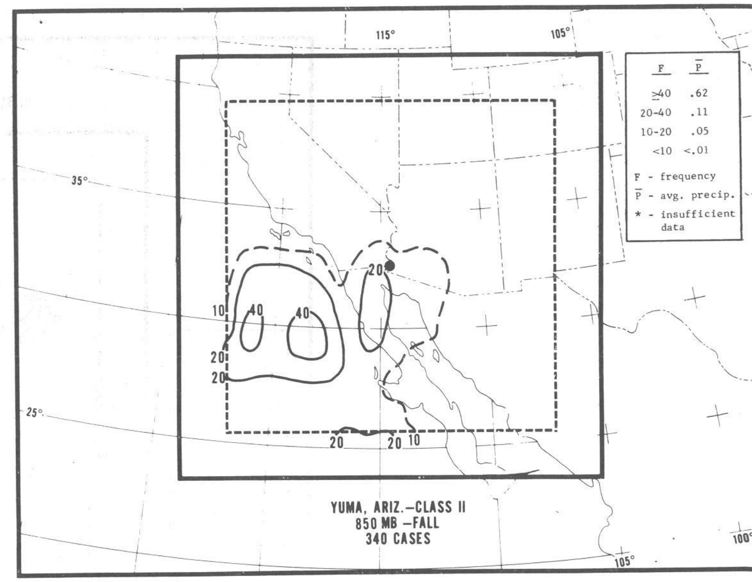

Chart 35—II

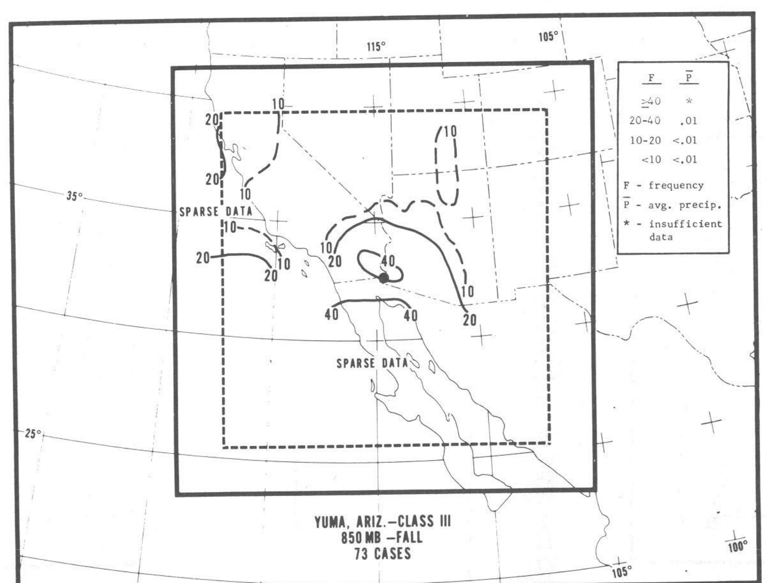

Chart 35—III

(Continued from inside front cover)

WBTM TDL 27 An Operational Method for Objectively Forecasting Probability of Precipitation. Harry R. Glahn and Dale A. Lowry, October 1969. (PB-188 660)

WBTM TDL 28 Techniques for Forecasting Low Water Occurrences at Baltimore and Norfolk. James M. McClelland, March 1970. (PB-191 744)

WBTM TDL 29 A Method for Predicting Surface Winds. Harry R. Glahn, March 1970. (PB-191 745)

WBTM TDL 30 Summary of Selected Reference Material on the Oceanographic Phenomena of Tides, Storm Surges, Waves, and Breakers. N. Arthur Pore, May 1970. (PB-193 449)

WBTM TDL 31 Persistence of Precipitation at 108 Cities in the Conterminous United States. Donald L. Jorgensen and William H. Klein, May 1970. (PB-193 599)

WBTM TDL 32 Computer-Produced Worded Forecasts. Harry R. Glahn, June 1970. (PB-194 262)

WBTM TDL 33 Calculation of Precipitable Water. L. P. Harrison, June 1970. (PB-193 600)

WBTM TDL 34 An Objective Method for Forecasting Winds Over Lake Erie and Lake Ontario. Celso S. Barrientos, August 1970. (PB-194 586)

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WBTM TDL 36 Current High Altitude Observations--Investigation and Possible Improvement. M. A. Alaka and R. C. Elvander, July 1970. (COM-71-00003)

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NWS TDL-37 Prediction of Surface Dew Point Temperatures. R. C. Elvander, February 1971. (COM-71-00253)

NWS TDL-38 Objectively Computed Surface Diagnostic Fields. Robert J. Bermowitz, February 1971. (COM-71-00301)

NWS TDL-39 Computer Prediction of Precipitation Probability for 108 Cities in the United States. William H. Klein, February 1971. (COM-71-00249)

NWS TDL-40 Wave Climatology for the Great Lakes. N. A. Pore, J. M. McClelland, C. S. Barrientos, and W. E. Kennedy, February 1971. (COM-71-00368)

NWS TDL-41 Twice-Daily Mean Monthly Heights in the Troposphere Over North America and Vicinity. August F. Korte, June 1971. (COM-71-00826)

NWS TDL-42 Some Experiments With a Fine-Mesh 500-Millibar Barotropic Model. Robert J. Bermowitz, August 1971. (COM-71-00958)

NWS TDL-43 Air-Sea Energy Exchange in Lagrangian Temperature and Dew Point Forecasts. Ronald M. Reap, October 1971. (COM-71-01112)

NWS TDL-44 Use of Surface Observations in Boundary-Layer Analysis. H. Michael Mogil and William D. Bonner, March 1972.

NWS TDL-45 The Use of Model Output Statistics (MOS) To Estimate Daily Maximum Temperatures. John R. Annett, Harry R. Glahn, and Dale A. Lowry, March 1972.

NWS TDL-46 SPLASH (Special Program To List Amplitudes of Surges From Hurricanes) I. Landfall Storms. Chester P. Jelesnianski, April 1972.

NWS TDL-47 Mean Diurnal and Monthly Height Changes in the Troposphere Over North America and Vicinity. August F. Korte and DeVer Colson, August 1972.

NWS TDL-48 Synoptic Climatological Studies of Precipitation in the Plateau States From 850-, 700-, and 500-Millibar Lows During Spring. August F. Korte, Donald L. Jorgensen, and William H. Klein, August 1972.