STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

# NOAA Technical Memorandum NWS TDL-48

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

## 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

Systems
Development
Office

SILV[illegible]ING, MD.

[illegible]ust 1972

## NOAA TECHNICAL MEMORANDA

### National Weather Service, Techniques Development Laboratory Series

The primary purpose of the Techniques Development Laboratory of the Office of Systems Development is to translate increases of basic knowledge in meteorology and allied disciplines into improved operating techniques and procedures. To achieve this goal, the laboratory conducts and sponsors applied research and development aimed at the improvement of diagnostic and prognostic methods for producing weather information. The laboratory performs studies both for the general improvement of prediction methodology used in the National Meteorological Service System and for the more effective utilization of weather forecasts by the ultimate user.

NOAA Technical Memoranda in the National Weather Service Techniques Development Laboratory series facilitate rapid distribution of material that may be preliminary in nature and which may be published formally elsewhere at a later date. Publications 1 to 5 are in the former series, Weather Bureau Technical Notes (TD), Techniques Development Laboratory (TDL) Reports; publications 6 to 36 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with TDL 37, publications are now part of the series NOAA Technical Memoranda, National Weather Service (NWS).

Publications listed below are available from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, Va. 22151. Price: $3.00 paper copy; $0.95 microfiche. Order by accession number shown in parentheses at end of each entry.

### ESSA Technical Memoranda

WBTM TDL 12 Charts Giving Station Precipitation in the Plateau States From 700-Mb. Lows During Winter. Donald L. Jorgensen, August F. Korte, and James A. Bunce, Jr., October 1967. (PB-176 742)

WBTM TDL 13 Interim Report on Sea and Swell Forecasting. N. A. Pore and W. S. Richardson, December 1967. (PB-177 038)

WBTM TDL 14 Meteorological Analysis of 1964-65 ICAO Turbulence Data. DeVer Colson, October 1968. (PB-180 268)

WBTM TDL 15 Prediction of Temperature and Dew Point by Three-Dimensional Trajectories. Ronald M. Reap, October 1968. (PB-180 727)

WBTM TDL 16 Objective Visibility Forecasting Techniques Based on Surface and Tower Observations. Donald M. Gales, October 1968. (PB-180 479)

WBTM TDL 17 Second Interim Report on Sea and Swell Forecasting. N. A. Pore and W. S. Richardson, January 1969. (PB-182 273)

WBTM TDL 18 Conditional Probabilities of Precipitation Amounts in the Conterminous United States. Donald L. Jorgensen, William H. Klein, and Charles F. Roberts, March 1969. (PB-183 144)

WBTM TDL 19 An Operationally Oriented Small-Scale 500-Millibar Height Analysis Program. Harry R. Glahn and George W. Hollenbaugh, March 1969. (PB-184 111)

WBTM TDL 20 A Comparison of Two Methods of Reducing Truncation Error. Robert J. Bermowitz, May 1969. (PB-184 741)

WBTM TDL 21 Automatic Decoding of Hourly Weather Reports. George W. Hollenbaugh, Harry R. Glahn, and Dale A. Lowry, July 1969. (PB-185 806)

WBTM TDL 22 An Operationally Oriented Objective Analysis Program. Harry R. Glahn, George W. Hollenbaugh, and Dale A. Lowry, July 1969. (PB-186 129)

WBTM TDL 23 An Operational Subsynoptic Advection Model. Harry R. Glahn, Dale A. Lowry, and George W. Hollenbaugh, July 1969. (PB-186 389)

WBTM TDL 24 A Lake Erie Storm Surge Forecasting Technique. William S. Richardson and N. Arthur Pore, August 1969. (PB-185 778)

WBTM TDL 25 Charts Giving Station Precipitation in the Plateau States From 850- and 500-Millibar Lows During Winter. August F. Korte, Donald L. Jorgensen, and William H. Klein, September 1969. (PB-187 476)

WBTM TDL 26 Computer Forecasts of Maximum and Minimum Surface Temperatures. William H. Klein, Frank Lewis, and George P. Casely, October 1969. (PB-189 105)

(Continued on inside back cover)

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

NOAA Technical Memorandum 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


Systems Development Office
Techniques Development Laboratory

SILVER SPRING, MD.
August 1972

UDC 551.589.1:551.577.36:551.515.127(78)"321"

| | | |
|---|---|---|
| 551.5 | | Meteorology |
| | .515 | Atmospheric disturbances |
| | | .127 Distribution of elements in upper air |
| | .577 | Precipitation |
| | | .36 Frequency of precipitation |
| | .589 | Synoptic climatology |
| | | .1 Frequency of elements associated with synoptic types |
| (78) | | Mountain and Plateau States |
| "321" | | Spring |

CONTENTS

# 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
Techniques Development Laboratory,
Systems Development Office, NOAA, Silver Spring, Md.

ABSTRACT. The synoptic climatology of precipitation over the Plateau States or intermountain region of the western part of the United States during spring, associated with 850-, 700-, and 500-mb Lows, is derived using 12-hr precipitation amounts (expressed as a percent of the 7-day normal) for 13 yr at 157 stations. The precipitation is initially related to nearby Low centers through a computer grid system of moving coordinates, resulting in precipitation patterns around each Low. The precipitation at each selected station is also related to the same set of nearby Low centers through a computer system of fixed coordinates, resulting in precipitation patterns around each station. The upper Lows are grouped into three intensity classes according to the departure from normal of their central heights. The average precipitation amount, distribution, and frequency of occurrence are derived and related to the level, intensity, and location of the upper Low. Probabilities of precipitation from each upper Low are derived for 35 stations. The use of the derived charts as forecast aids is discussed. The geographical distribution of the upper Lows is shown for each level. It is found that precipitation appears to be specified best by the most intense Lows at the 700-mb level and that the spring season data differ significantly from those of the winter season. Considerable variability is shown to exist among several stations.

## 1. INTRODUCTION

Experienced meteorologists in the western part of the United States recognize that the number of upper Lows affecting weather in the Plateau States or intermountain region of the western part of the country (fig. 1) increases as time progresses from winter into spring. However, the area over which these storms generate precipitation, from the standpoint of both frequency of occurrence and of amounts, is not well known. We undertook this investigation to examine the manner in which these cyclones and their associated precipitation differ with season.

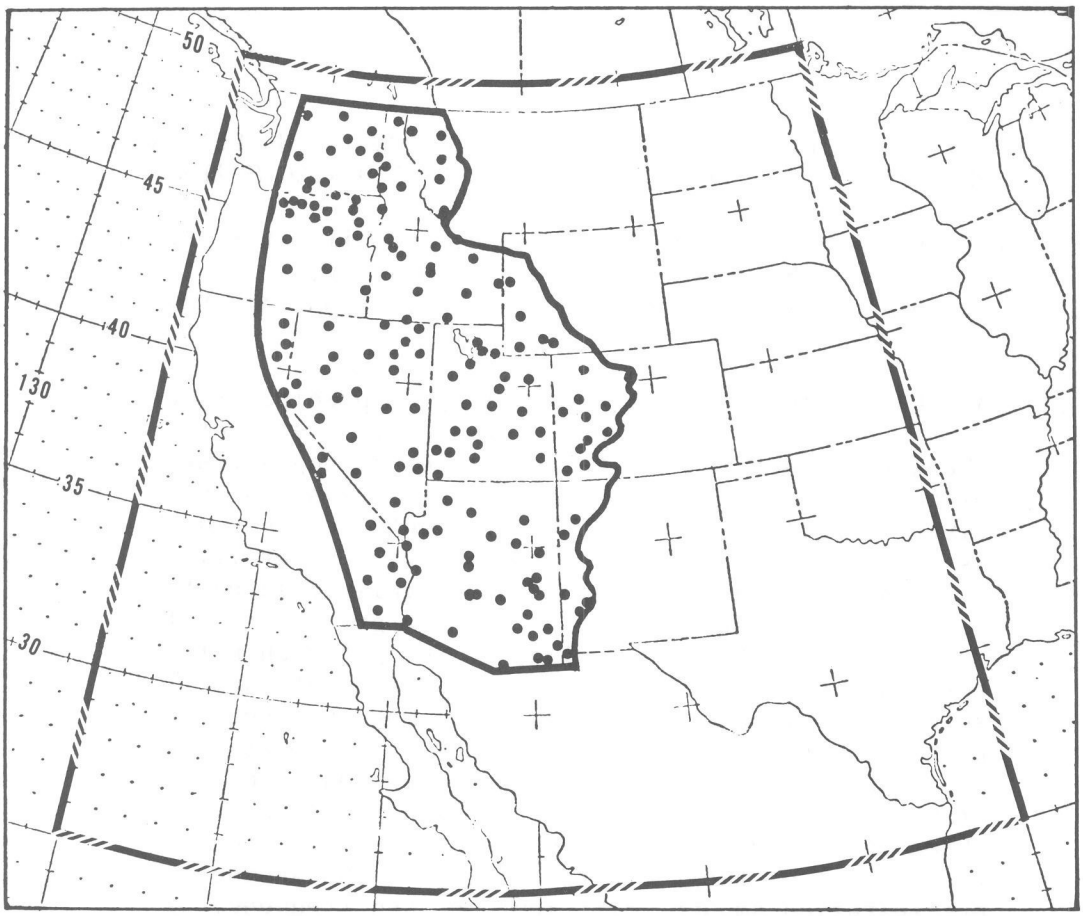



Figure 1.--Observational area (enclosed by the heavy dashed lines) from which the upper Low data were obtained and the precipitation station network (heavy black dots)

Thus, this study is an investigation into a synoptic climatology during spring, relating precipitation in the Plateau States or Intermountain West to upper cyclones. It is a supplement to the completed investigation into a synoptic climatology during winter by Jorgensen et al. 1966, 1967a, 1967b; Klein et al. 1968; and Korte et al. 1969.

## 2. PRECIPITATION PATTERNS RELATIVE TO THE CENTERS OF LOWS

Results of this part of the investigation indicate that significant differences exist in weather patterns obtained for spring compared to those for winter. These results are presented to illustrate the general distribution of precipitation occurrence and amounts around the upper cyclones at 850-, 700-, and 500-mb levels. An analysis of data for a selection of individual stations, similar to that performed for the winter season (Jorgensen et al. 1967b and Korte et al. 1969), also is presented.

### A. Data and Procedures

The period of record (1952 through 1964) is the same for this study as for the earlier ones. Positions and intensities of upper Lows occurring within the observational area (fig. 1) were tabulated for March, April, and May; the

precipitation data associated with each Low were gathered for 157 recording stations in the Intermountain West. Hourly precipitation amounts were obtained from the National Climatic Center (NCC) at Asheville, N.C., and summed for the 12-hr periods centered at the times of the upper air observations.

Figure 1 depicts the observational area and the locations of the 157 recording stations. To reduce the effort required for the recovery of precipitation data and to carry out the computer processing, we reduced the number of stations from 280 used in the earlier studies to 157 in this study. This reduction continues to furnish a uniform distribution of stations throughout the recording area.

As shown in figure 2, the grid employed remains unchanged. It consists of 324 cells or 1° latitude squares. For investigating precipitation relative to cyclonic centers, the origin is positioned at the Low center; thus, the grid moves with the center. The computer then examines the occurrence or nonoccurrence of precipitation reported from the recording stations and allocates the occurrence (or nonoccurrence) to the appropriate cell in which the station is located. In addition, average amounts of precipitation occurring in the grid cells are computed. When investigating precipitation received at individual stations, the grid is centered on the station and remains stationary.

Positions of the upper Lows were read to within 0.5° latitude and longitude. Their intensities were indicated by taking the departure from normal (DN) values of their central heights. The Lows were then grouped into three classes by dividing the overall range of intensities into three nearly equal intervals. Class I represents weak cyclones; class II, those of intermediate intensity; and class III, the most intense Lows. Table 1 gives the class limits for the three levels.

The number of Lows in each class and the total number of classes are given in table 2. The 1,613 Lows occurring at the 850-mb level during spring (92 days) greatly exceed the 1,110 Lows observed at this level during winter (90 days); the 1,262 cases observed in spring at the 700-mb level may be compared to the 872 cases tabulated at this level during winter. At the 500-mb level, there were 875 Lows during winter compared to 1,178 during spring. Thus when comparing the frequency of Lows in spring to that in winter, there are spring increases of 45 percent at the 850-mb level, 45 percent at the 700-mb level, and 35 percent at the 500-mb level.

At the 850-mb level, 30 percent of the cases occurred in March; 32 percent occurred in April; and 38 percent occurred in May. Similar percentages for the 700-mb level are 28, 33, and 39; at the 500-mb level, corresponding percentages are 27, 32, and 41. It is seen, therefore, that a gradual trend toward an increasing frequency of occurrence of Lows at all three levels is observed during spring.

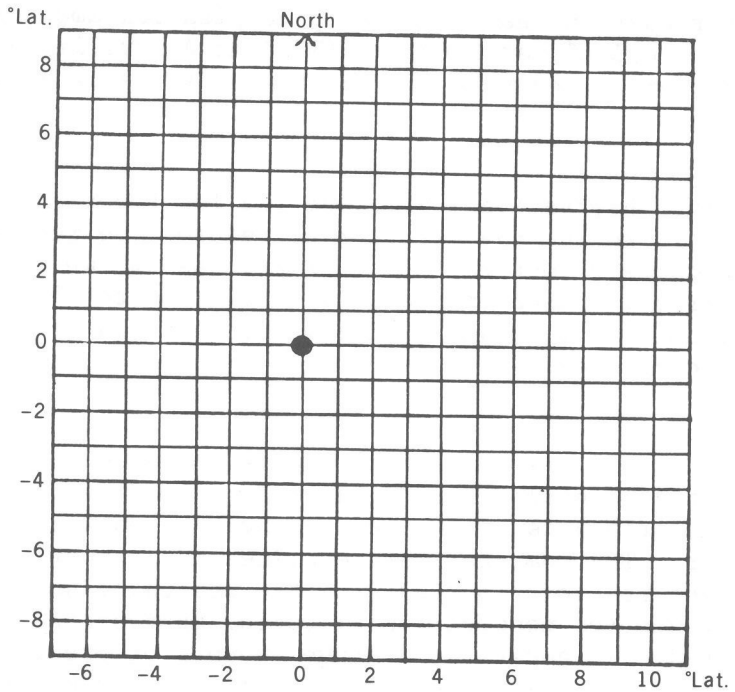



Figure 2.--Grid system of great circles on the spherical earth with dimensional units equivalent to latitude degrees along the two axes

Table 1.--Class limits (in m) of departures from normal of the central heights for Lows at the three levels

| Level (mb) | Class I | Class II | Class III |
|---|---|---|---|
| 850 | > -30 | -30 to -120 | < -120 |
| 700 | > -30 | -30 to -122 | < -122 |
| 500 | > -50 | -50 to -220 | < -220 |

Table 2.--Number of Lows investigated at each level and in each class during spring for the period 1952 through 1964

| Level (mb) | Class I | Class II | Class III | All classes |
|---|---|---|---|---|
| 850 | 314 | 951 | 348 | 1,613 |
| 700 | 246 | 598 | 418 | 1,262 |
| 500 | 201 | 745 | 232 | 1,178 |

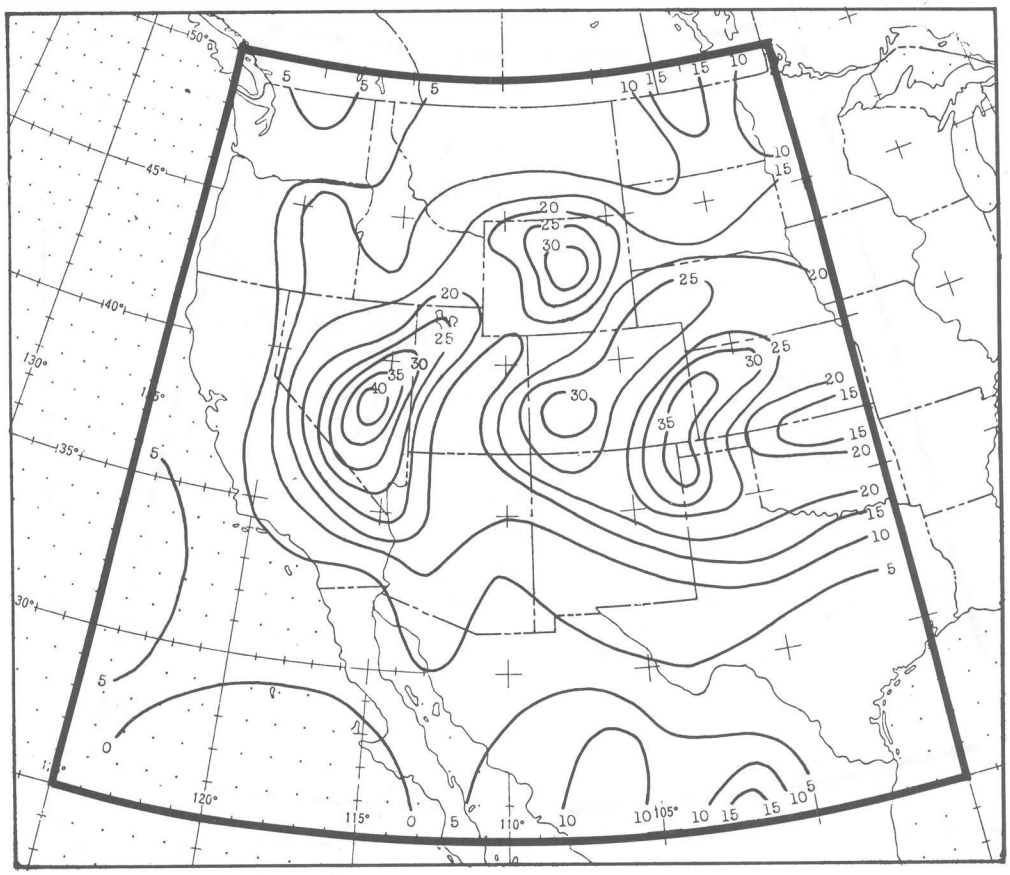



Figure 3.--Distribution of 850-mb Lows over the observational area during spring (March 1952 through May 1964). The frequencies are analyzed as the total number of occurrences per 2° latitude square.

## B. Areal Distribution of Upper Lows

The upper Lows tabulated at the 850-, 700-, and 500-mb levels in the observational area (fig. 1) have been analyzed to determine their areal distribution. This was accomplished by counting the number of Lows of all intensities occurring in 2° latitude squares over the area and analyzing these totals (figs. 3-5).

Figure 3 depicts the distribution of Lows at the 850-mb level. The analysis indicates four areas of maximum occurrence with the area of most frequent occurrence over Nevada and secondary maxima over the Oklahoma Panhandle, western Colorado, and central Wyoming. The centers of maximum occurrence at this level appear to be largely influenced by the underlying topography and occur generally to the lee of the higher mountain ranges.

The distribution of Lows at the 700-mb level is shown in figure 4. The most frequent occurrence is over extreme southwestern Nebraska; the second most intense center is over central California. Several weaker centers are

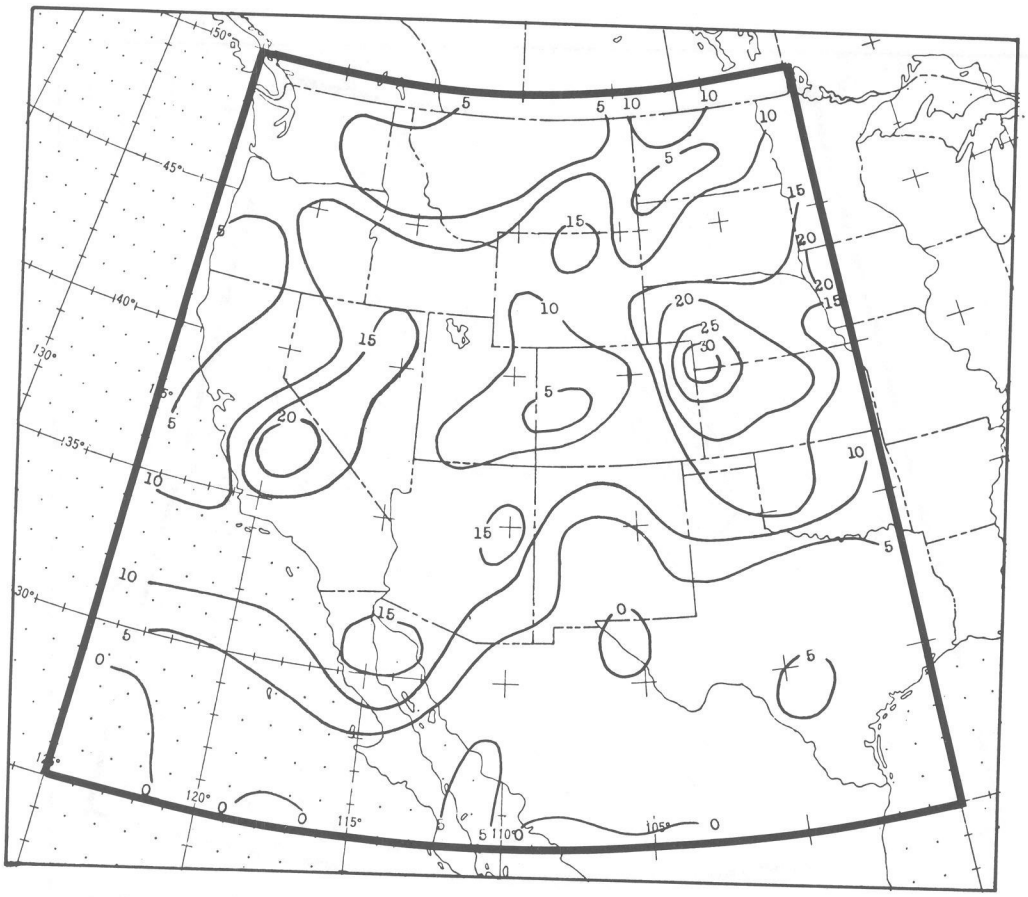


Figure 4.--Same as figure 3 except this is for the 700-mb Lows

scattered across the observational area. The center over southwestern Nebraska is about 3.5° north-northeast of the 850-mb center over the Oklahoma Panhandle, indicating a northward slope of the cyclones toward colder air. The center over California, on the other hand, is about the same distance (3.5°) west-southwest of the 850-mb center over Nevada. Thus, colder air aloft in the California area tends to be to the southwest of the 850-mb center. A minimum is observed in western Colorado; it does not have an easily recognizable counterpart at the lower level.

The distribution of Lows at the 500-mb level is shown in figure 5. At this higher level, the tendency for Lows to occur in specific areas is less marked. The area of most frequent occurrence is over the interior of central California; a second, smaller area is situated over southeastern Idaho. Elsewhere, the centers of activity are not well-defined. The center over California appears to be associated with a similar center at the 700-mb level, but the small center over Idaho is not visible at the lower level. On the other hand, the center at 700 mb over southwestern Nebraska does not make a significant appearance at the 500-mb level.

It is interesting to compare the areal distribution of upper Lows for spring with those derived for winter (Klein et al. 1968). In addition to a substantial increase in the number of Lows observed at all levels, there are significant variations in their distributions.

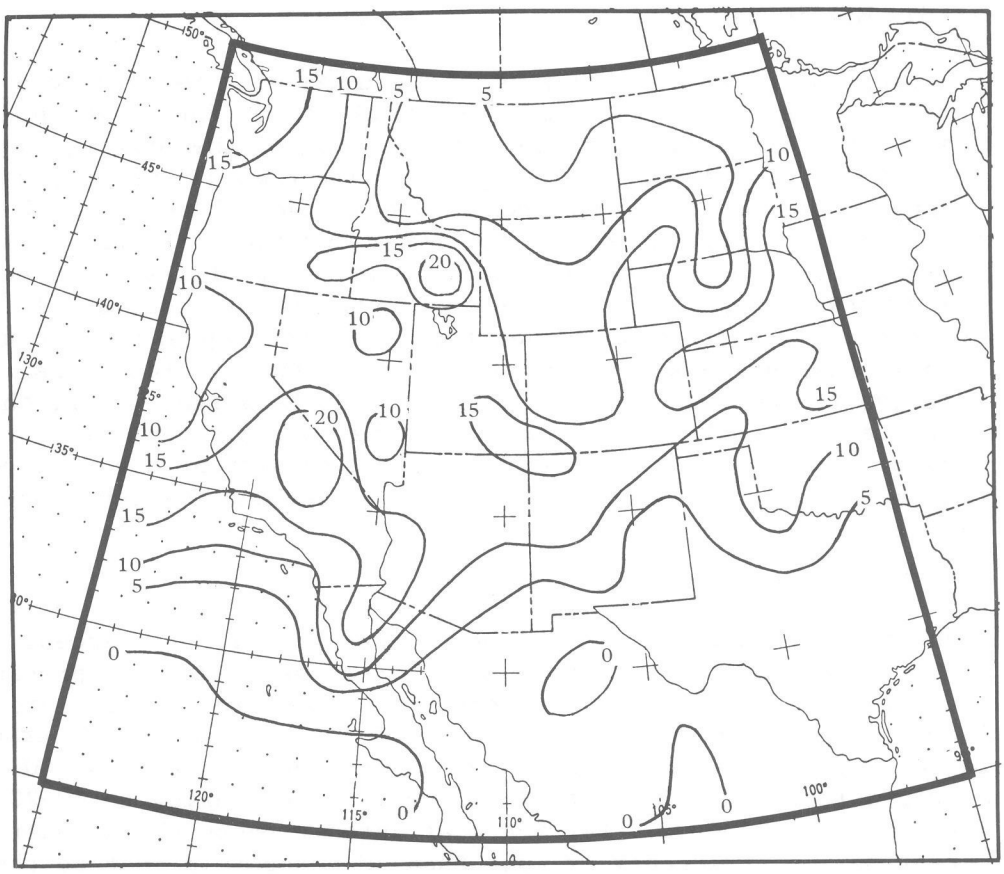



Figure 5.--Same as figure 3 except this is for the 500-mb Lows

At the 850-mb level, there is a fourfold increase in the number of Lows occurring over Nevada in spring compared to those in winter. The areas of maximum occurrence over the Oklahoma Panhandle and central Wyoming exist during both seasons, but occurrences are substantially more frequent in spring. The spring maximum over western Colorado is not visible in the winter pattern. At the 700- and 500-mb levels, the differences are less pronounced. In the Far West, the areas of maximum occurrence of upper Lows appear to shift northward as time progresses from winter into spring. This shift is indicated by the weakening during spring of the centers of maximum frequencies observed during winter at both the 700- and 500-mb levels over the extreme northern part of the Gulf of California. Only residual centers remain in this area in spring, with the areas of maximum occurrence shifting northward to central California. The center of maximum occurrence at the 700-mb level over southeastern Nebraska during both seasons shows little change in position as time progresses from winter into spring, but it does increase in intensity.

## C. Frequency of Precipitation

To investigate the frequency of occurrence of precipitation around the Low centers, we centered the grid (fig. 2) on the cyclone and allowed it to move with the center. The cases in each cell were then examined by computer for the three intensity classes for the 850-, 700-, and 500-mb levels to determine the relative frequency with which precipitation occurred within the grid area surrounding the Low center. These data were then plotted and analyzed to obtain the frequency charts presented in the next three topics.

## Frequency at 850 Millibars

Charts depicting the relative frequency of occurrence of measurable precipitation ($\geq$0.01 in.) in relation to the Low center at 850 mb for three intensity classes are shown in figure 6. With the Low centered at the origin, figure 6A shows the frequency of occurrence in the grid area for weak Lows (class I). Frequencies range from zero over the eastern and southern borders of the grid to slightly more than 10 percent in the northwest quadrant. Figure 6B shows a similar analysis for the Lows of intermediate intensity (class II); and figure 6C illustrates the pattern for the most intense Lows (class III). Over all portions of the grid, it is seen that the relative frequency of occurrence increases with increasing intensity of the cyclonic center. For class II cyclones, relative frequencies range from 10 percent to slightly more than 40 percent in the area about 3° west-northwest of the cyclonic center. For the class III cases, frequency values range from about 20 percent near the edges of the grid to more than 60 percent in the area of maximum frequency about 2° northwest of the center.

## Frequency at 700 Millibars

The three charts in figure 7 are the same as those in figure 6 except that they show the analyses for the 700-mb level. For class I cases, a precipitation frequency of slightly more than 20 percent is observed near the grid origin with values dropping to less than 10 percent over much of the grid area. For the intermediate class, a maximum frequency somewhat higher than 40 percent is near the origin (the cyclonic center) with values decreasing to 10-20 percent near the edges of the grid. For the most intense cases shown under class III, a center of maximum frequency of more than 70 percent is just to the northeast of the origin; an area of more than 20 percent covers most of the grid.

When comparing the 700-mb patterns with those obtained for the 850-mb level, somewhat higher values in the centers of maximum frequency are observed at the higher level with a shift of the centers being 2° to 3° toward the east or southeast. This indicates a slope with height toward a northwesterly direction of the cyclonic centers between the two levels.

## Frequency at 500 Millibars

Figure 8 depicts frequency distributions of precipitation around the position of the 500-mb cyclone that are similar to those for the two lower levels in figures 6 and 7. Centers of maximum frequency range from nearly 25 percent for the weakest Lows to approximately 45 percent for the Lows of intermediate intensity to slightly more than 50 percent for the most intense Lows. Again, the centers are shifted 1° or 2° toward the east or northeast when compared to the 700-mb positions, indicating a further slope upward toward a westerly or southwesterly direction of the axis of the upper cyclone.

## Seasonal Changes

When comparing the frequency patterns of precipitation for spring in figures 6 through 8 with those for winter (Klein et al. 1968), significant differences are noted. The major differences appear as a result of variations in the intensities of the centers of maximum frequency and in their locations relative to the cyclonic centers.

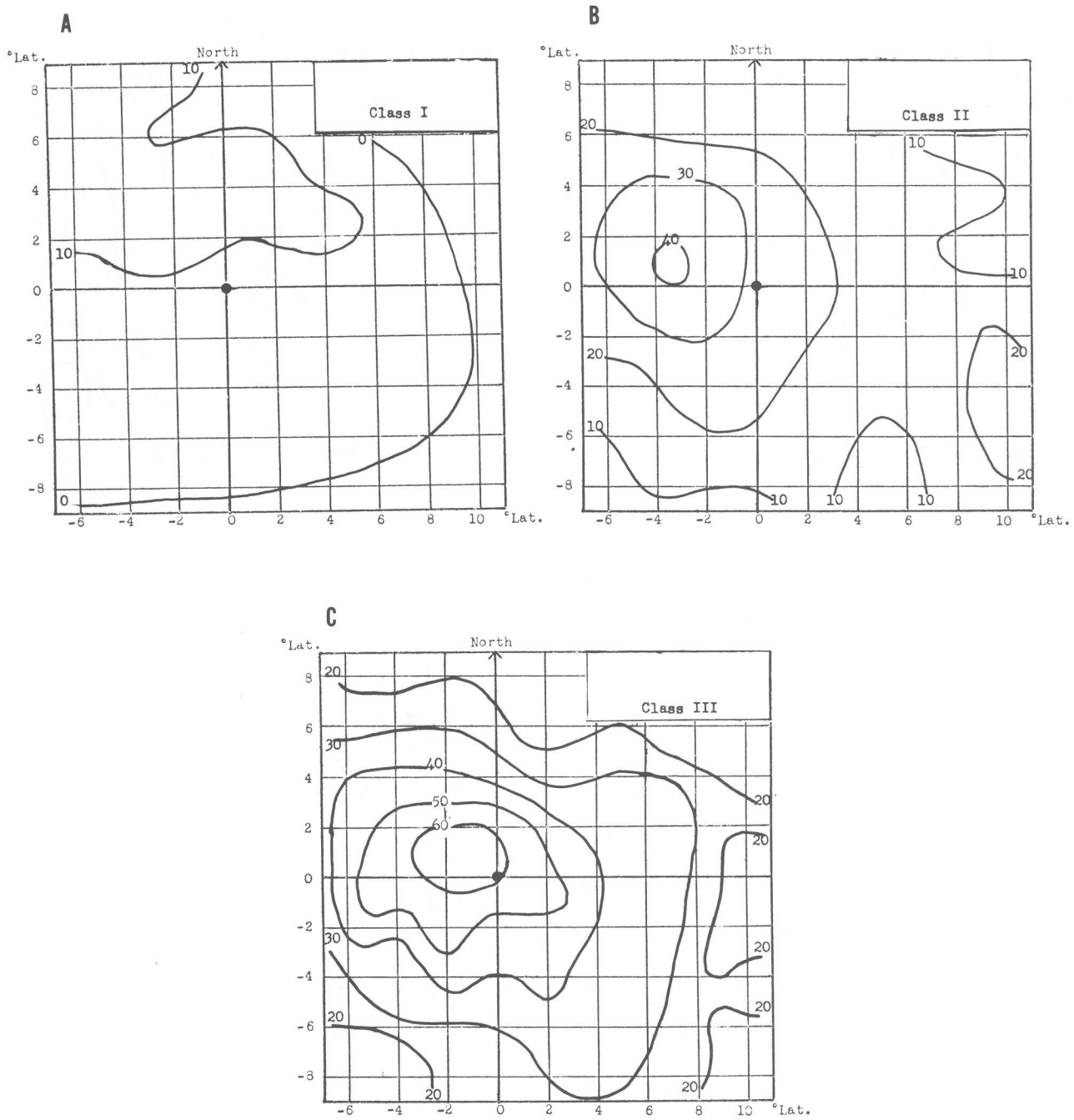



Figure 6.--Relative frequency of occurrence during spring of measurable precipitation (≥0.01 in.) for 12-hr periods centered at observation times for the 850-mb Lows located at the origin of the grid

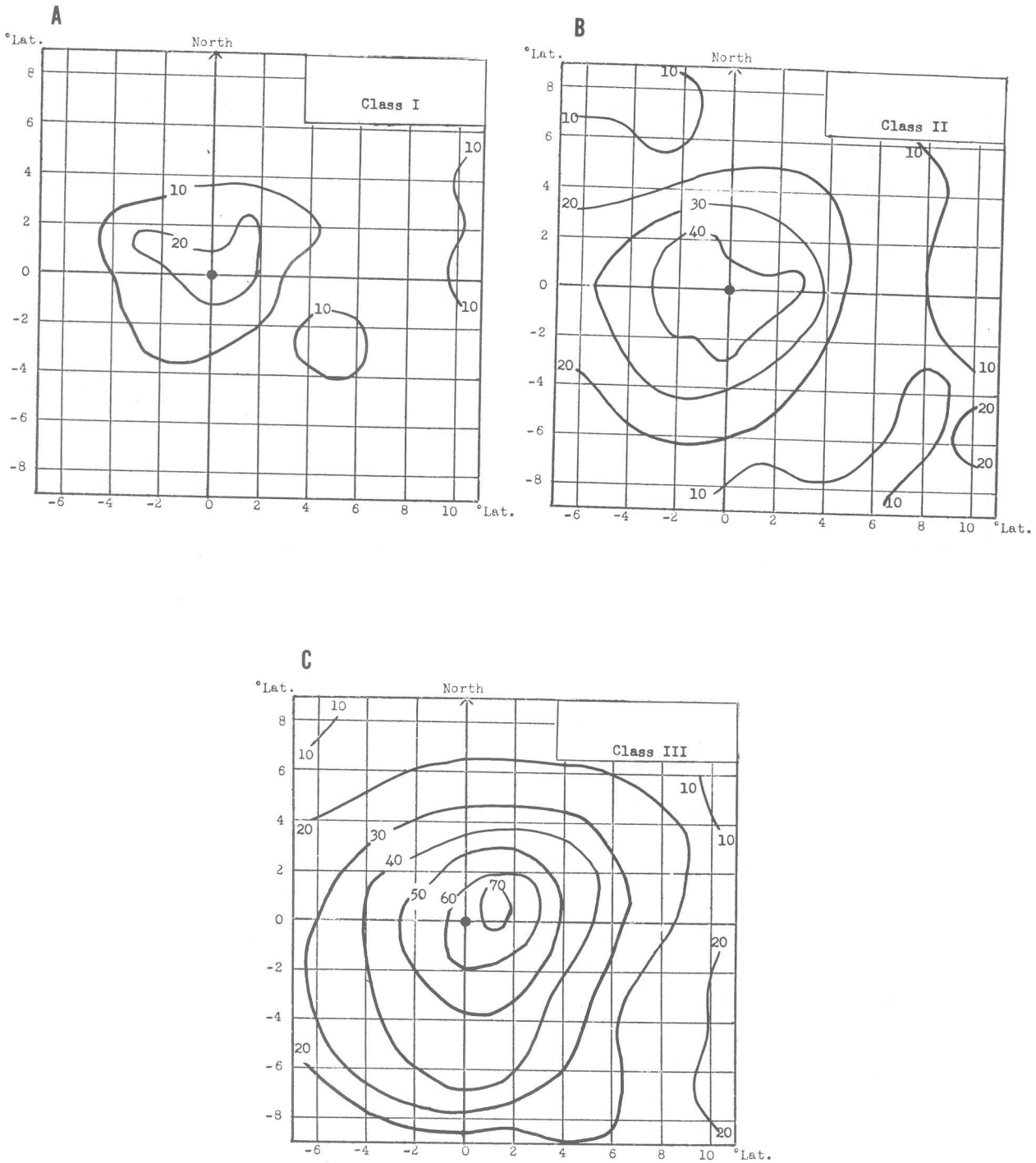



Figure 7.--Same as figure 6 except this is for the 700-mb Lows

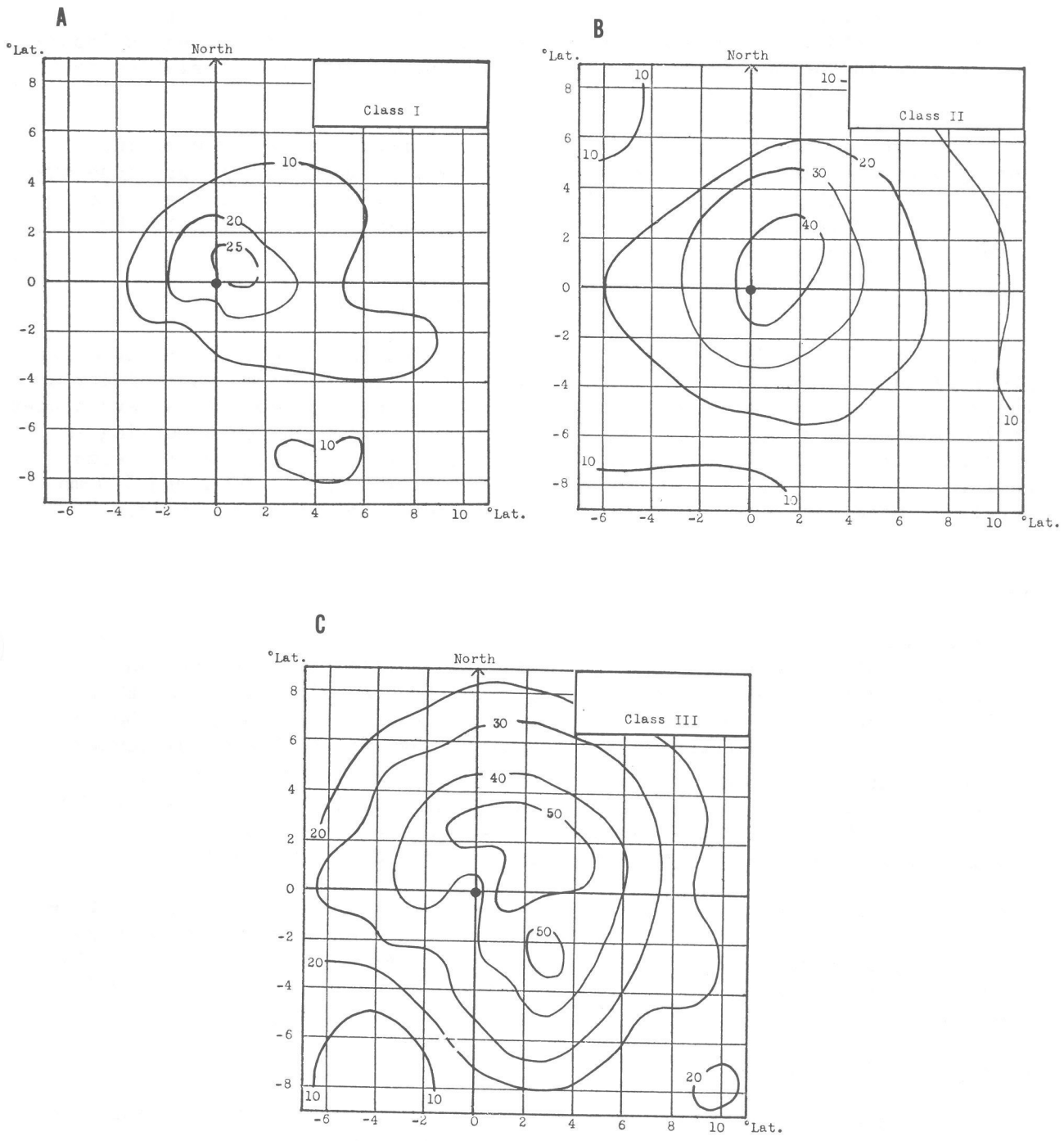



Figure 8.--Same as figure 6 except this is for the 500-mb Lows

In general, the relative frequency of precipitation is somewhat less in spring than in winter for comparable class intervals. An exception to this trend is the greater frequency observed in spring for class I centers at the 500-mb level. This may reflect a tendency for showers to occur. As winter changes to spring, the centers of maximum occurrence are shifted from 1° to 4° toward the northwest quadrant. This shift has the effect of making an important change in the position of the most frequent precipitation relative to the position of the Low center.

The changes in the frequency patterns as time proceeds from winter into spring appear to indicate differences of sufficient magnitude to preclude the combination of the two seasons. These differences, no doubt, reflect the changing characteristics in the structure of storms progressing into the warmer spring season.

## D. Average Amounts of Precipitation

Charts similar to those showing relative frequencies have been prepared for 12-hr amounts of precipitation. To include the climatological variability at individual stations, we have expressed the precipitation amounts as percentages of 7-day station normals. Percentage amounts of precipitation occurring in each cell are accumulated by computer, and an average is obtained for each cell for the three intensity classes for Lows at the 850-, 700-, and 500-mb levels. These data were then plotted and analyzed to obtain the charts presented in the next three topics.

### Average Precipitation at 850 Millibars

Patterns of precipitation amounts for this level are given in figure 9. The class I situations show only a small area of precipitation greater than 10 percent. A rather broken pattern is obtained for the class II cases that include several small centers of precipitation ranging to just above 30 percent. The class III pattern is also rather irregular, with several centers of precipitation scattered throughout the area, two of which reach the 50-percent value. This pattern irregularity is not visible for Lows at the 700- and 500-mb levels (see the next two topics) and probably results from storm centers that are not as well organized at the 850-mb level.

Corresponding patterns of relative frequency of precipitation for the three intensity classes in figure 6 show much less irregularity than for precipitation amounts. A comparison of the two sets of charts indicates that greater amounts of precipitation tend to occur toward the eastern or warm sectors of the storms.

### Average Precipitation at 700 Millibars

Quantitative precipitation patterns for this level are given in figure 10. Except for minor variations, the patterns of precipitation amounts are relatively smooth when compared to those for the 850-mb level. Amounts range up to 10-15 percent for the class I Lows and to slightly above 40 and 60 percent, respectively, for the class II and III Lows.

Comparing the quantitative patterns shown in figure 10 with those for frequencies of occurrence in figure 7 indicates that the centers of maximum values nearly coincide in the two sets of charts.

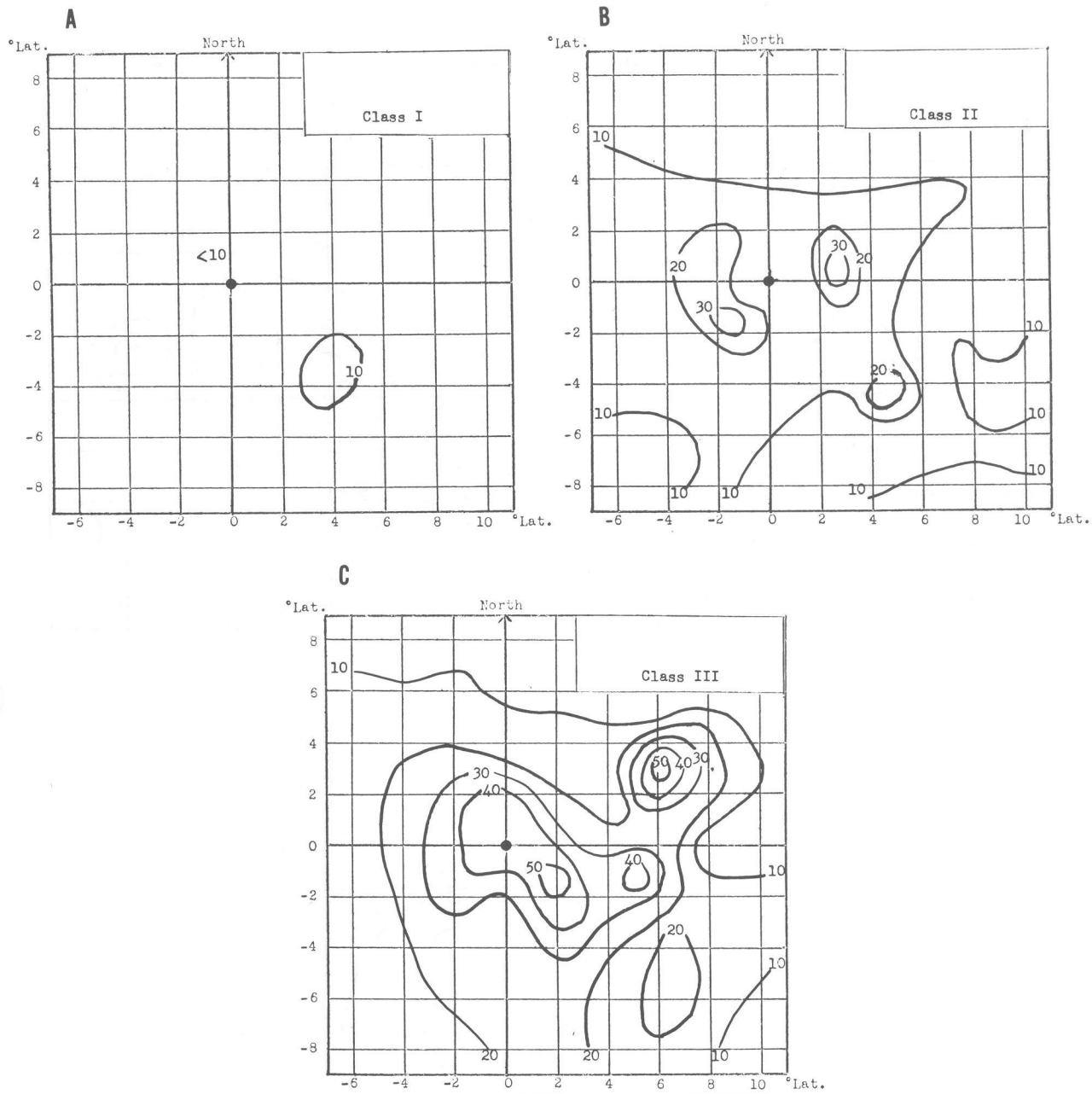



Figure 9.--Average precipitation amounts observed during spring for the 850-mb Lows located at the origin. The amounts occurring during the 12-hr period centered at the upper air observation times are expressed as percentages of the 7-day station normals.

Average Precipitation at 500 Millibars

Charts for this level are presented in figure 11. Centers of maximum amounts of precipitation range from slightly more than 15 percent for class I Lows to 30 percent for Lows in class II to 50 percent for Lows in class III. Except for class I, these values are slightly less than those for the 700-mb level.

As with the 700-mb level, the quantitative patterns coincide quite closely with the frequency patterns.

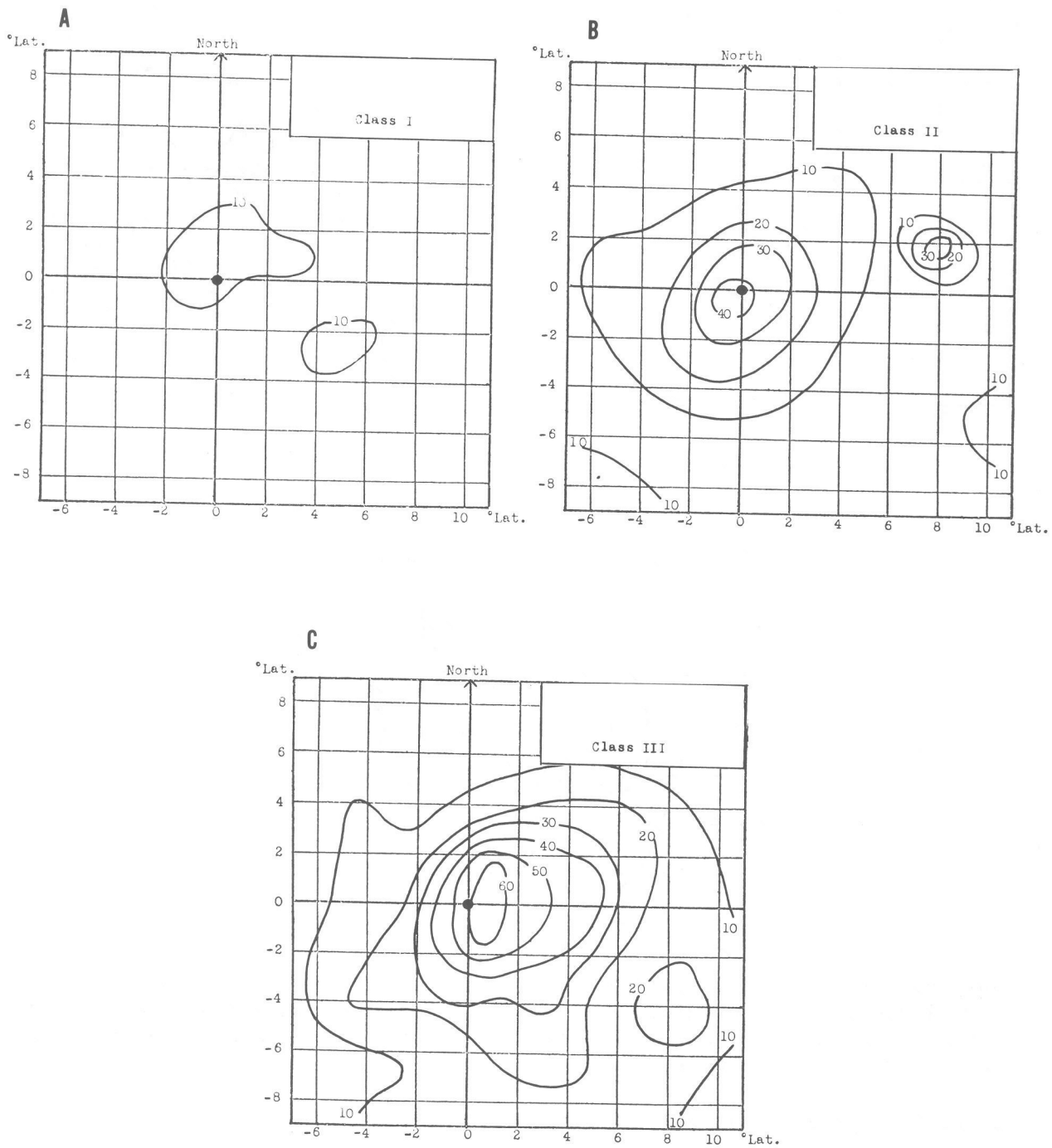



Figure 10.--Same as figure 9 except this is for 700-mb Lows

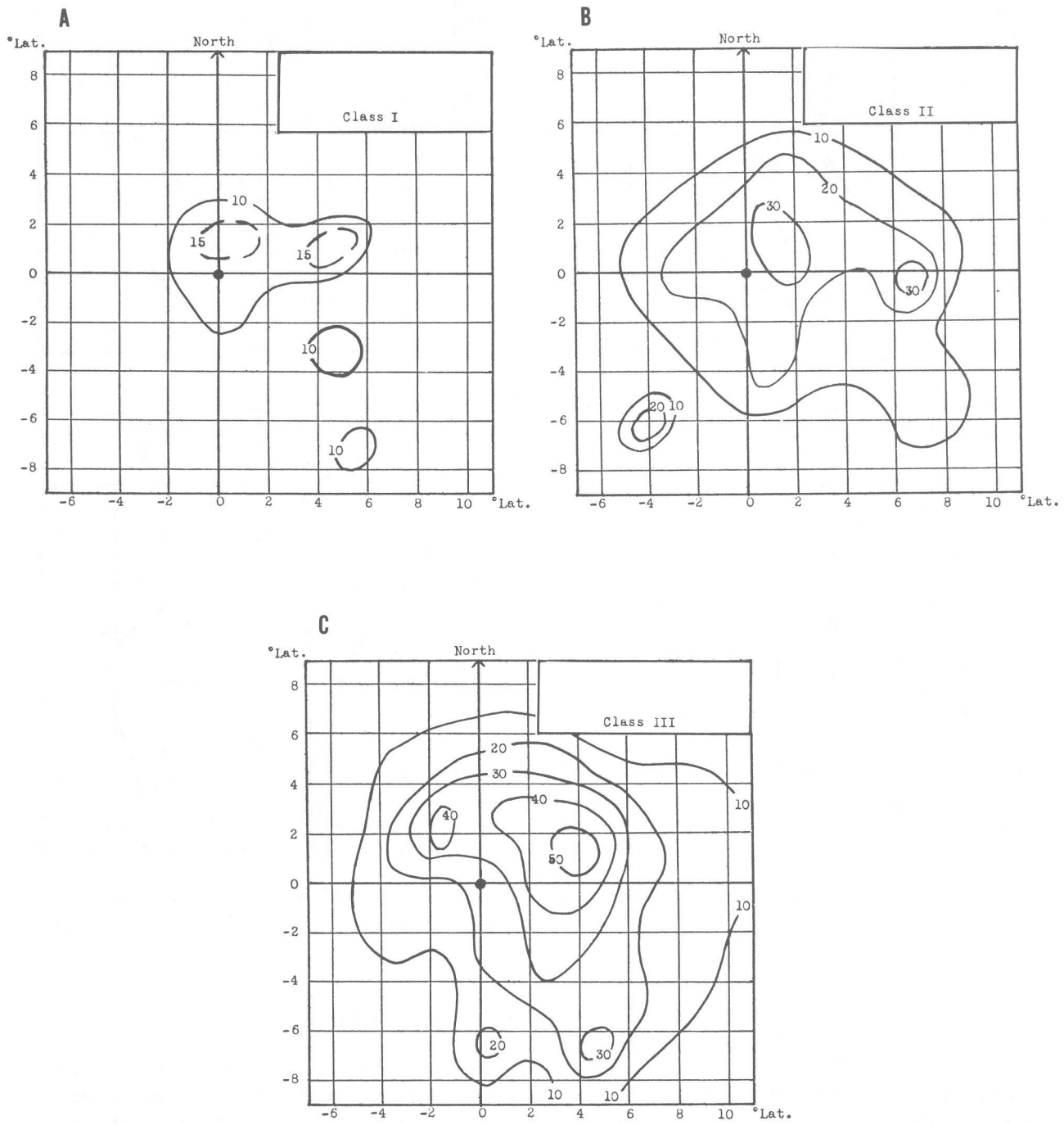



Figure 11.--Same as figure 9 except this is for 500-mb Lows

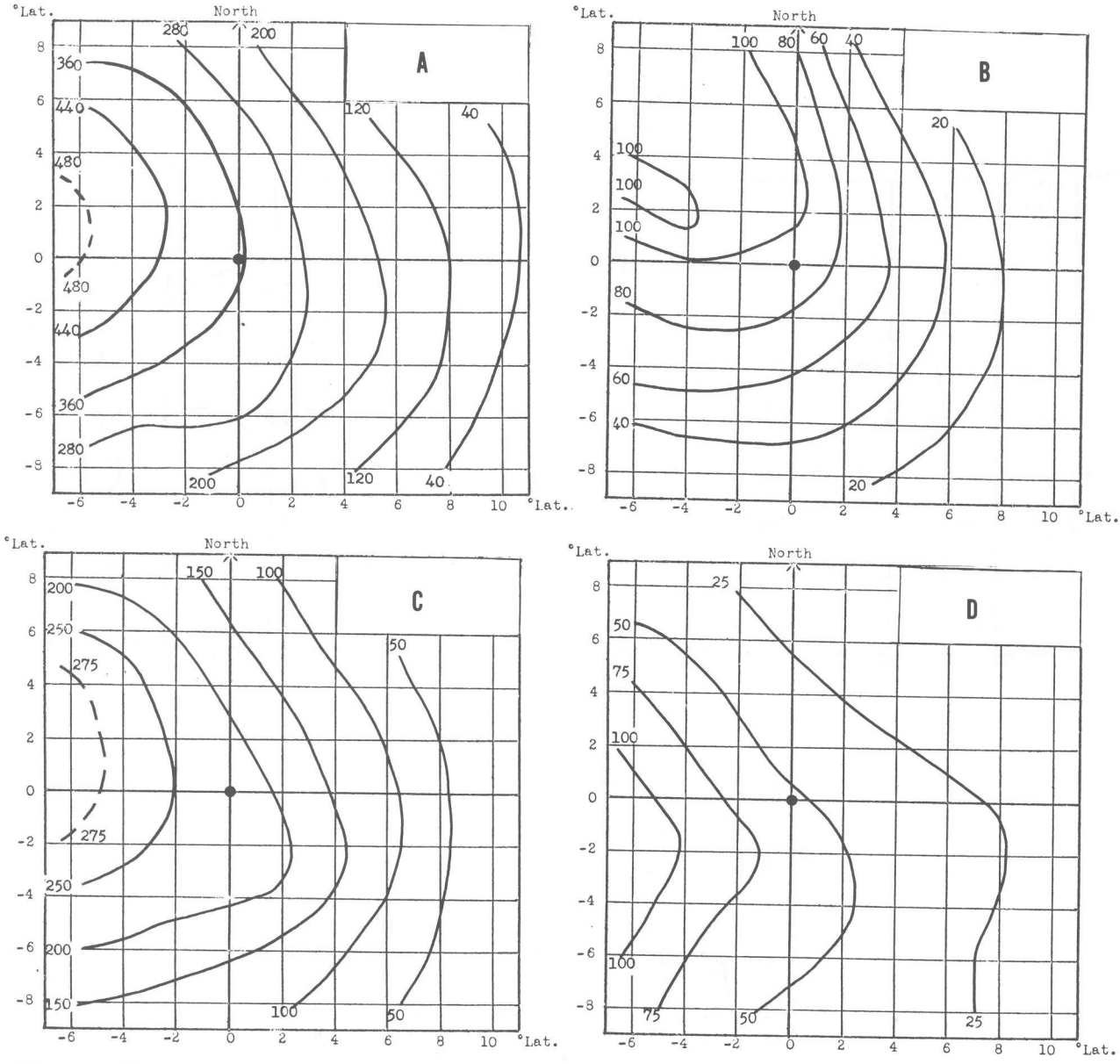



Figure 12.--Analyses showing the number of cases per 1° x 1° cell at 850 mb during spring for (A) all Lows combined, (B) class I Lows, (C) class II Lows, and (D) class III Lows

## E. Data Amounts Used in the Analysis

For each Low centered at the origin of the grid, only that portion of the grid over the precipitation station network could have precipitation cases allocated to each affected cell. A precipitation case consisted of one or more stations reporting precipitation within the cell. The amount for each observation credited to the cell consisted of the average of all stations reporting within it. The total number of cases recorded per cell is related to the observation periods the cell is over the observation network and to the density of the stations there.

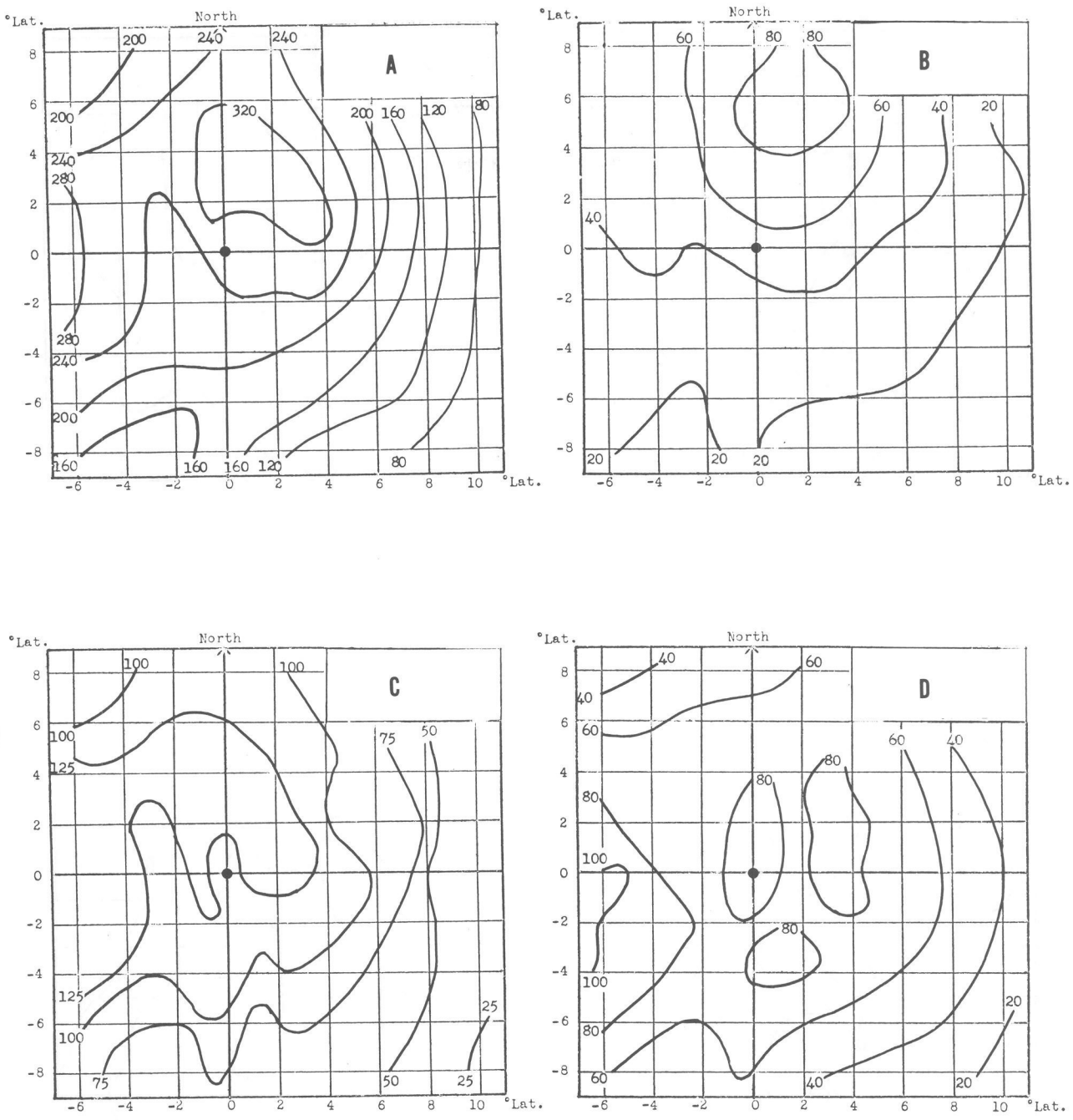



Figure 13.--Same as figure 12 except this is for 700-mb Lows

Figures 12, 13, and 14 show the number of cases per cell for each level studied. In general, they indicate that most of these cases were concentrated about 6° of latitude to the west of the Low at the 850- and 700-mb levels. However, at 700 mb and 500 mb, a maximum appears about 3° of latitude northeast of the Low representing all classes. Data distributions are also shown for each class at each level.

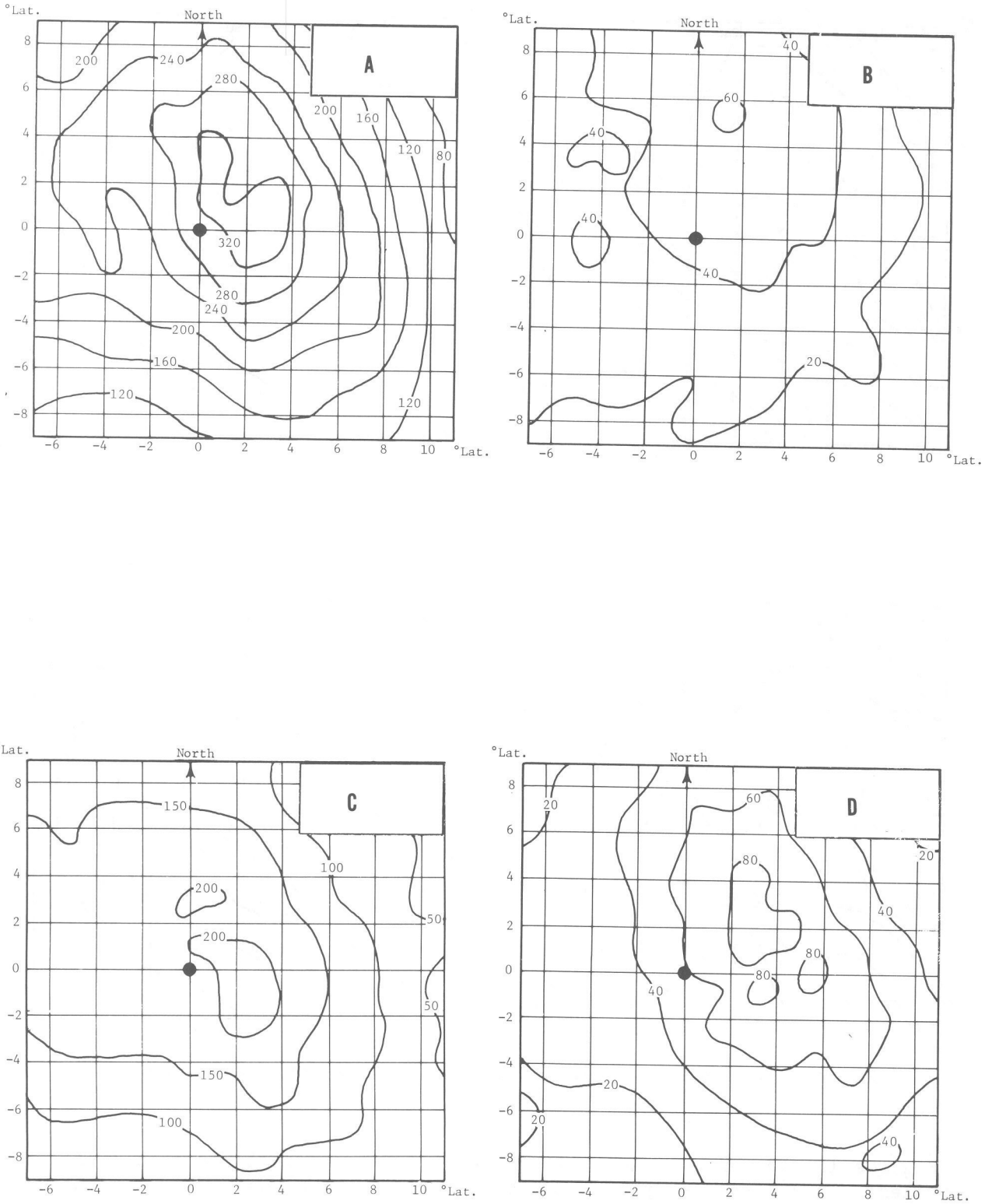



Figure 14.-- Same as figure 12 except this is for 500-mb Lows

## 3. STATION PRECIPITATION PROBABILITIES

In this section are the results of the remainder of the investigation concerning the same Lows associated with precipitation during spring as described in section 2. Earlier investigations (Jorgensen et al. 1967b and Korte et al. 1969) include the results of similar studies concerning Lows during winter. In section 2, significant differences are shown to exist in the general precipitation patterns around Low centers in spring compared to those in winter. Similar results are noted when the spring and winter precipitation probabilities are compared for several stations.

### A. Data and Procedures

The source, period of record, Lows, classes of Lows, recorded precipitation, station network, and observational area are the same as those in section 2. The grid is the same (fig. 2); but the origin is now at the center of the grid. The origin is then positioned on the station instead of on the Low as was the case when the moving grid was used. The stationary grid incorporates both the topography surrounding the station and the dynamics of the storm. The moving grid is used to study generalized results of the storm's dynamics over a larger area; the stationary grid is used for a specific location.

The precipitation from Lows in the grid area was processed and summarized by computer at the NCC. The amount of precipitation recorded at the station was assigned to the grid cell where the related Low was located. The percentage of precipitation occurrences in each cell represents the probability of precipitation occurrence at the station when the Low was in this position. The arithmetic mean of precipitation amounts in each grid cell was tabulated with the corresponding number of observation periods.

The station charts shown in the appendix depict the probability patterns of the occurrence of measurable precipitation at each station. These patterns were obtained by smoothing the data in a similar manner to that described by Petterssen (1965) in which data are averaged within overlapping squares of variable sizes. The resulting averages were located at the approximate centroid of the data in each square; isopleths were then drawn and subjectively smoothed.

### B. Derived Charts and Forecasting

Some results of this investigation are shown in the charts in the appendix. Charts for four of the 35 stations analyzed are discussed to illustrate the synoptic climatology of precipitation probabilities at each station. Average precipitation amounts related to each probability contour interval have been computed and are entered as tabular insets within all of the charts. For the stations and their corresponding chart numbers, see table 3 in the appendix. Thus in chart 13-Ia, the "13" represents Flagstaff, Ariz.; the "I" represents the class of Lows, and the "a" represents the 850-mb level.

Flagstaff, Ariz. (Charts 13-a, 13-b, and 13-c)

As shown by our winter charts for this station (Jorgensen et al. 1967b and

Korte et al. 1969), there is considerable change in precipitation probabilities when class I situations at each level are compared to the related class II and class III situations. In all cases for both winter and spring, the precipitation probabilities for the more intense Lows (class III) are greater than those for the less intense Lows (class I). For the same intensity class during winter, the 850-mb chart generally indicates a greater specification of precipitation than the 700- or 500-mb upper level. However during spring, the 700- and 500-mb levels generally indicate the higher specification of precipitation.

The Flagstaff charts for winter compared to those for spring indicate that the maxima for class I (weak) and class II (moderate) Lows at 500 mb show an increase in the specification of precipitation probability. The probability area of 20 percent or greater has increased during spring. This increase at 500 mb for all classes may be due to an increase in the number of higher level cold cut-off Lows occurring near here during spring than in winter.

Salt Lake City, Utah (Charts 30-a, 30-b, and 30-c)

Comparison of our winter charts (Jorgensen et al. 1967b and Korte et al. 1969) with the spring charts for this station indicates again that the precipitation probabilities during both seasons for the more intense Lows (class III) are greater than those for the less intense Lows (class I). Also, for the same intensity class, there is a similarity aloft to the trend noted at Flagstaff when corresponding winter and spring charts are compared. The specification of precipitation at the 500- and 700-mb levels generally exceeds that at the 850-mb level during spring. During winter, the 850-mb level usually indicated the largest specification of precipitation probability. Possibly, the 500-mb cold cut-off Lows during spring are responsible for this situation as noted in the discussion of Flagstaff.

The positions of upper Lows that produce a maximum precipitation probability at the station usually are located northwest to east-northeast of the city for the most intense situations. The pattern was not as consistent for all levels during winter as in spring. According to Williams (1967), "Because of the high Wasatch Range to the east of Salt Lake City, post-cold-frontal precipitation continues much longer than at stations with no orographic effect." Thus, a similar orographic effect may be taking place here.

El Centro, Calif. (Charts 9-a, 9-b, and 9-c)

Inspection of the charts for this station indicates again that the intense Lows (class III) specify the precipitation probabilities the best at all levels during winter and spring. During both seasons, except for moderate (class II) Lows at 700 mb in spring, all the class II and III Lows show maxima off southwestern California. None of the weak (class I) Lows indicate significant precipitation probabilities. At 700 mb, the class III maximum over Arizona during winter does not appear during the similar situation in spring; but a class II maximum does appear during the occurrence of moderate Lows in spring over Arizona-California. It is interesting to note that, at El Centro, the class II 850-mb Lows specify higher maximum precipitation probabilities in winter than in spring.

Craig, Colo. (Charts 5-a, 5-b, and 5-c)

When this station is compared to Salt Lake City and Flagstaff, similar trends are noted aloft in the comparison of both weak to more intense Lows and higher to lower levels for the same intensity class. Again, generally, the better specification of precipitation probability occurs with the most intense (class III) Low and at the 700-mb level within an intensity class.

It is interesting to note that the high probability (80 percent) of precipitation for weak (class I) Lows obtained at 850 mb in our winter study (Korte et al. 1969) has decreased to 20 percent during spring. Variations are also noted when other corresponding levels for the winter and spring season on these charts are compared. These variations suggest that the data for the two seasons at a corresponding level and intensity can not be combined.

Use of the Derived Charts in Forecasting

The procedure for using the derived charts (see the appendix) as a forecast aid for each of the 35 stations and for weather modification research was described in a paper by Korte et al. 1969. It is repeated here for completeness, with appropriate modifications to obtain current normal heights for each Low. Tabular insets of average precipitation amounts pertaining to each probability contour interval are shown on the station charts.

In an earlier study (Jorgensen et al. 1967b), probability charts for 700-mb Lows at a station also were discussed as forecast aids and for weather modification research. The charts presented in the appendix can be used in similar ways. They give a first estimate of the average measurable precipitation and the related probability from Lows at either the 850-, 700-, or 500-mb level during spring.

We suggest that the charts in the appendix be applied by using the following procedure; the forecasters's best judgment, however, is always an overriding consideration.

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).

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 (Korte and Colson 1972a). The difference between the observed and normal heights (observed minus normal) in meters gives the DN values.

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 from the corresponding intensity class chart for the station is included on each chart.

4. If there are probabilities derived from more than one concurrent level and class of Low, choose the largest probability available.

The derived charts have been provided to the headquarters of the Western Region of the National Weather Service in Salt Lake City for operational tests and evaluation. Similar charts have been derived describing 850-mb Lows for the fall season (Korte and Colson 1972b). The summer season may require a different approach because considerable precipitation in the Plateau States may occur from convective activity unrelated to a Low center.

## 4. SUMMARY

This investigation about the synoptic climatology of precipitation during spring associated with 850-, 700-, and 500-mb Lows over the Intermountain West has shown the following results. Patterns of precipitation frequencies and percentage amounts during spring around upper Low centers and around selected station locations were derived for three intensity classes of Lows. The geographical distribution of these Lows are found to be greater during spring at all levels when compared to similar earlier studies for winter. The majority of Lows generally occur during spring over Nevada and from Wyoming to northern Texas at 850 mb; over southwest Nebraska and central California at 700 mb; and southeastern Idaho and central California at 500 mb.

The relative frequency and corresponding percentage amount of measurable precipitation about each of the Low centers generally increases over the grid area with increasing intensity of the cyclonic center. Higher values of these maxima are found at 700 mb than at 850 mb and 500 mb. The quantitative amount and corresponding frequency precipitation patterns usually agree well when compared. In general, the relative frequency of precipitation, and often the related percentage amount, is somewhat less in spring than in winter for comparable class intervals. Significant differences exist in the general precipitation patterns around Low centers in spring when compared to winter.

The probability of precipitation charts for the 35 stations show both interesting differences and similarities; the charts suggest that the seasonal precipitation probabilities differ enough so that each should be treated individually. Only a few stations have been discussed. A general inspection of all the charts indicates that the highest probability of precipitation at

850-, 700-, and 500-mb levels occurs with class III (intense) Lows. However, at approximately 20 stations, the class II (moderate) Lows show almost as high a probability of precipitation as do the class III Lows. Only about four stations indicate the class I (weak) Lows with almost as high a probability of precipitation as the other two classes of Lows (e.g., see charts 29-b and 29-c).

For class III and class II Lows at most of the stations, the probability of precipitation is about the same at the 700- and 850-mb levels. In the case of class I Lows at many stations, the probability of precipitation is considerably greater at 700 mb than at 850.

The interested reader should see Korte and Colson (1972b) for a comparable investigation describing 850-mb Lows at these stations in the fall.

## ACKNOWLEDGMENTS

This investigation was accomplished partly through the financial support of the U.S. Department of the Interior, Bureau of Reclamation. Computer processing of data was handled by the National Climatic Center, Asheville, N.C. Normal maps at 850, 700, 500, and 300 mb were calculated by Frank Lewis and Clifton K. S. Chun of the Techniques Development Laboratory. Assistance in manually processing data was provided by James A. Bunce, Jr., James R. Noffsinger, and Margaret A. Dalton of the Techniques Development Laboratory. Thanks are also due to DeVer Colson for a careful reading of the manuscript.

## REFERENCES

Jorgensen, Donald L., Klein, William H., and Korte, August F., "A Synoptic Climatology of Winter Precipitation From 700-Mb Lows for Intermountain Areas of the West," Technical Note 45-TDL-4, Techniques Development Laboratory, Weather Bureau, Environmental Science Services Administration, U.S. Dept. of Commerce, Washington, D.C., May 1966, 25 pp.

Jorgensen, Donald L., Klein, William H., and Korte, August F., "A Synoptic Climatology of Winter Precipitation From 700-Mb Lows for Intermountain Areas of the West," Journal of Applied Meteorology, Vol. 6, No. 5, Oct. 1967a, pp. 782-790 (condensed version of the first reference).

Jorgensen, Donald L., Korte, August F., and Bunce, James A., Jr., "Charts Giving Station Precipitation in the Plateau States From 700-Mb Lows During Winter," ESSA Technical Memorandum WBTM TDL-12, Techniques Development Laboratory, Weather Bureau, Environmental Science Services Administration, U.S. Dept. of Commerce, Silver Spring, Md., Oct. 1967b, 18 pp. and 34 charts.

Klein, William H., Jorgensen, Donald L., and Korte, August F., "Relation Between Upper Air Lows and Winter Precipitation in the Western Plateau States," Monthly Weather Review, Vol. 96, No. 3, Mar. 1968, pp. 162-168.

Korte, August F., "Twice-Daily Mean Monthly Heights in the Troposphere Over North America and Vicinity," NOAA Technical Memorandum NWS TDL-41, Techniques Development Laboratory, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, Silver Spring, Md., June 1971, 31 pp.

Korte, August F., and Colson, DeVer, "Mean Diurnal and Monthly Height Changes in the Troposphere Over North America and Vicinity," NOAA Technical Memorandum NWS TDL-47, Techniques Development Laboratory, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, Silver Spring, Md., Aug. 1972a, 30 pp.

Korte, August F., and Colson, DeVer, "Synoptic Climatological Studies of Precipitation in the Plateau States From 850-Millibar Lows During Fall," NOAA Technical Memorandum NWS TDL-49, Techniques Development Laboratory, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, Silver Spring, Md., Aug. 1972b, 56 pp.

Korte, August F., Jorgensen, Donald L., and Klein, William H., "Charts Giving Station Precipitation in the Plateau States From 850- and 500-Millibar Lows During Winter," ESSA Technical Memorandum WBTM TDL 25, Techniques Development Laboratory, Weather Bureau, Environmental Science Services Administration, U.S. Dept. of Commerce, Silver Spring, Md., Sept. 1969, 9 pp. and appendixes A and B.

Petterssen, Sverre, Weather Analysis and Forecasting: Volume II. Weather and Weather Systems, 2d Ed., McGraw Hill Book Co., Inc., New York, N.Y., 1965, 266 pp. and 7 plates.

Williams, Philip, Jr., "Station Descriptions of Local Effects on Synoptic Weather Patterns," ESSA Technical Memorandum WBTM WR-5 (revised), Weather Bureau Western Region, Environmental Science Services Administration, U.S. Dept. of Commerce, Salt Lake City, Utah, Nov. 1967, 55 pp.

## 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 spring at the 850-, 700-, and 500-mb levels (a, b, and c) 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 | | | |

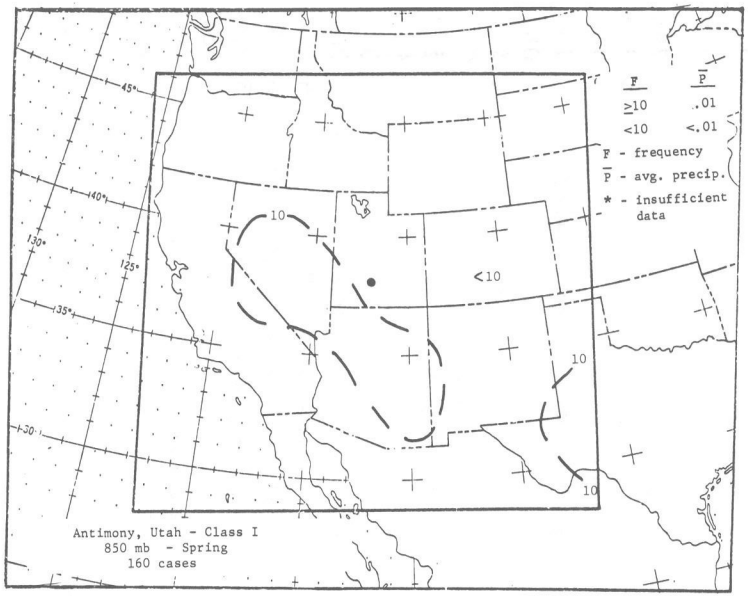



Chart 1 - Ia

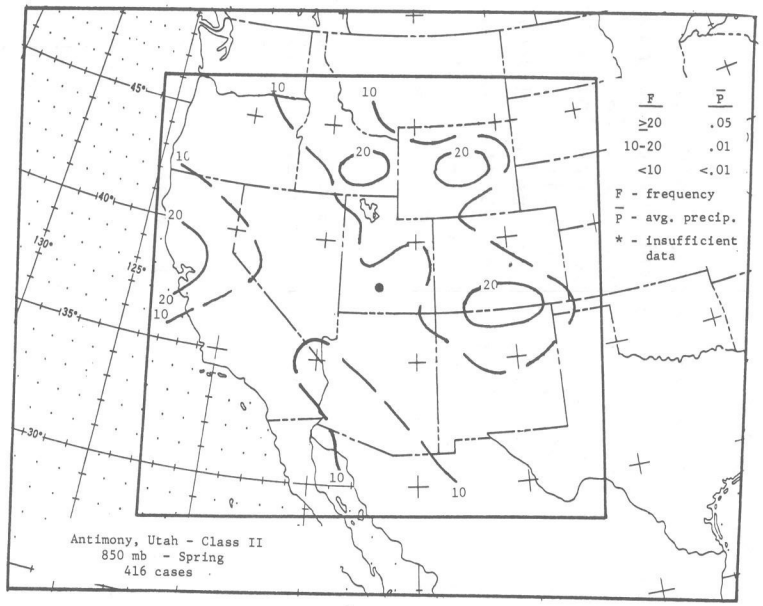



Chart 1 - IIa

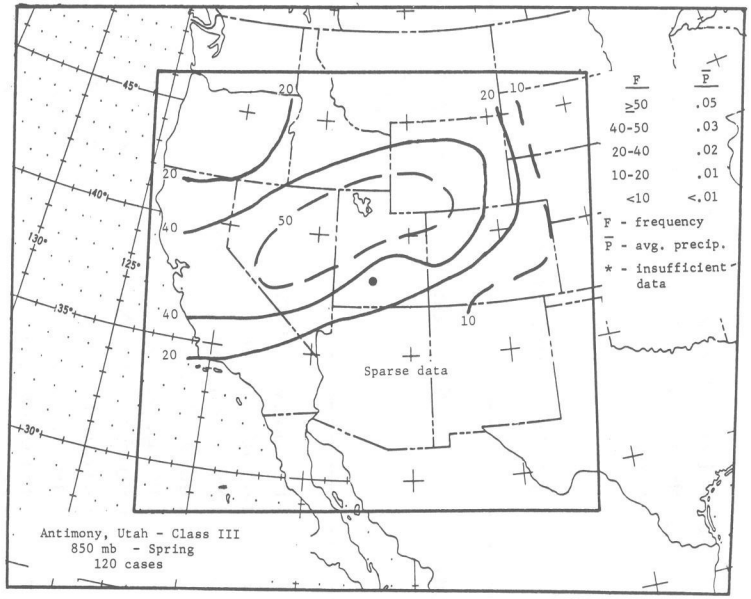



Chart 1 - IIIa

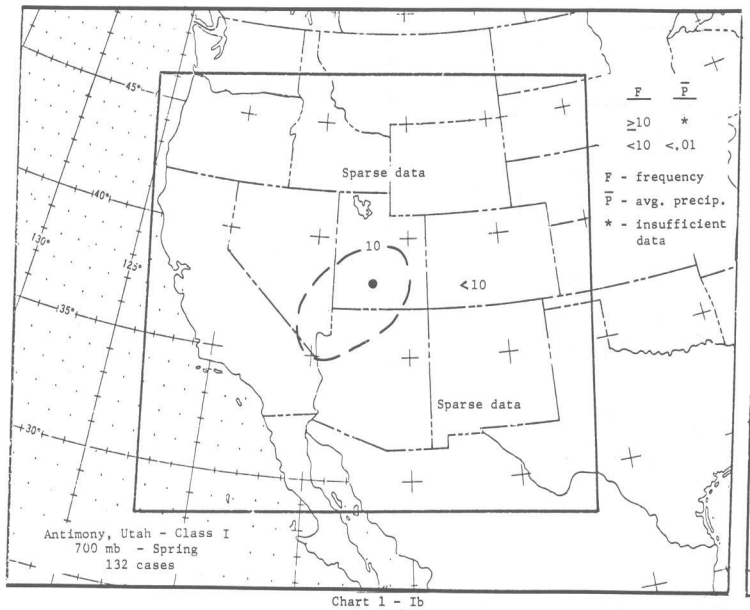



Chart 1 - Ib

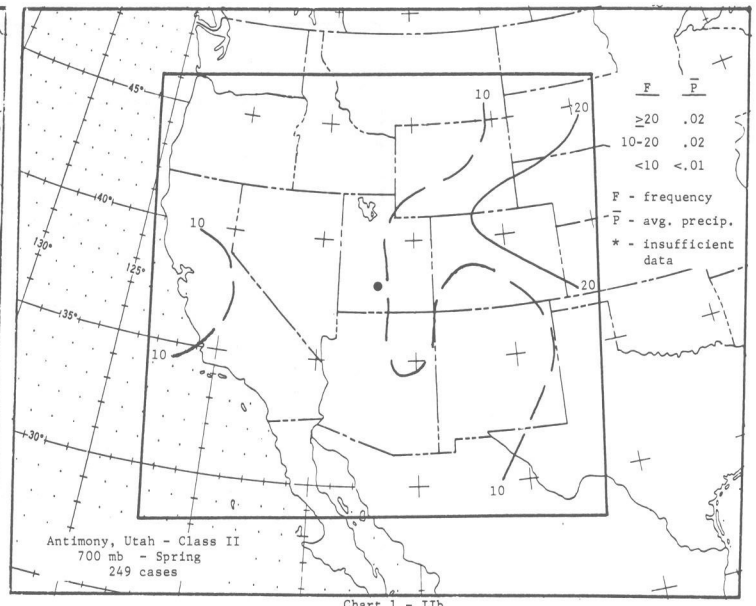



Chart 1 - IIb

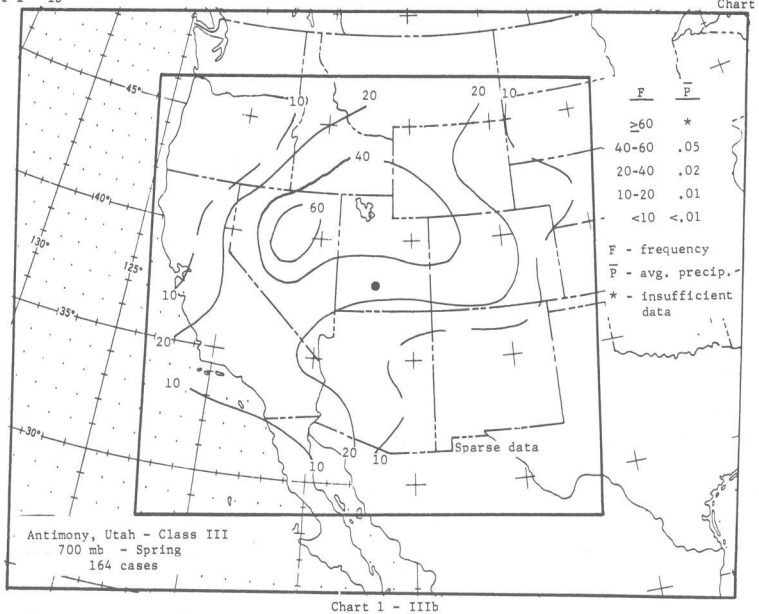



Chart 1 - IIIb

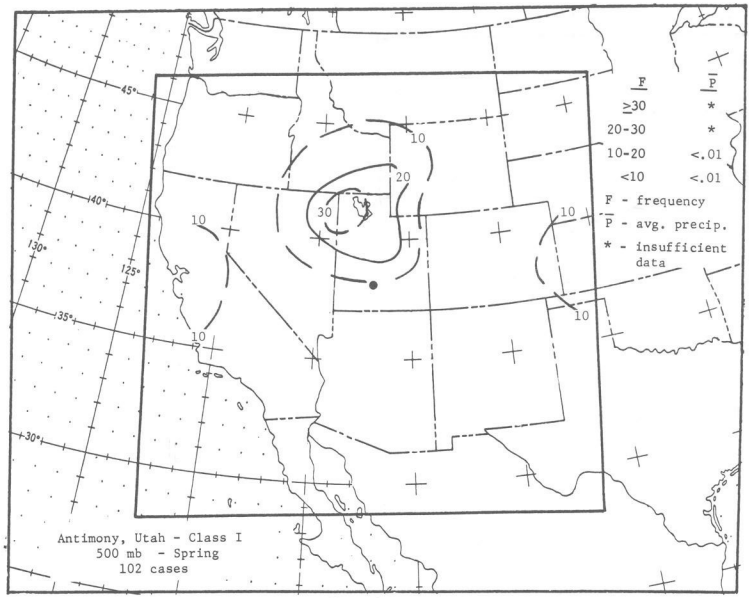



Chart 1 - Ic

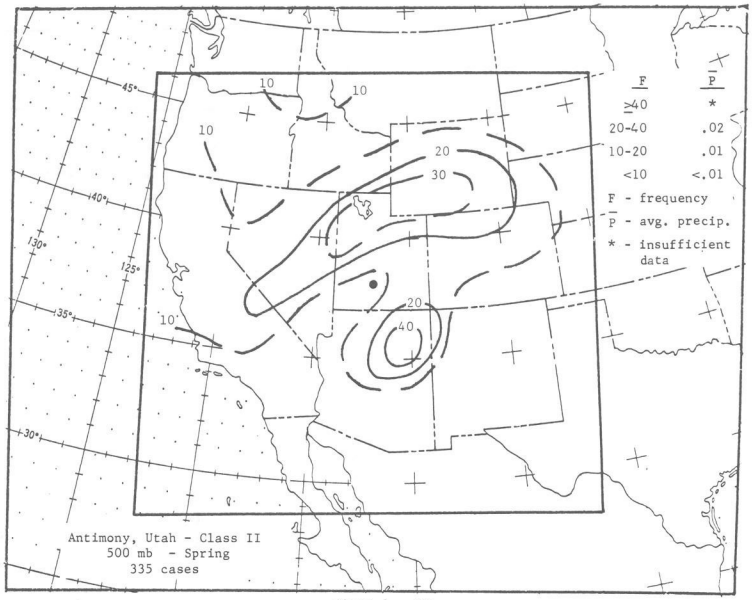



Chart 1 - IIc

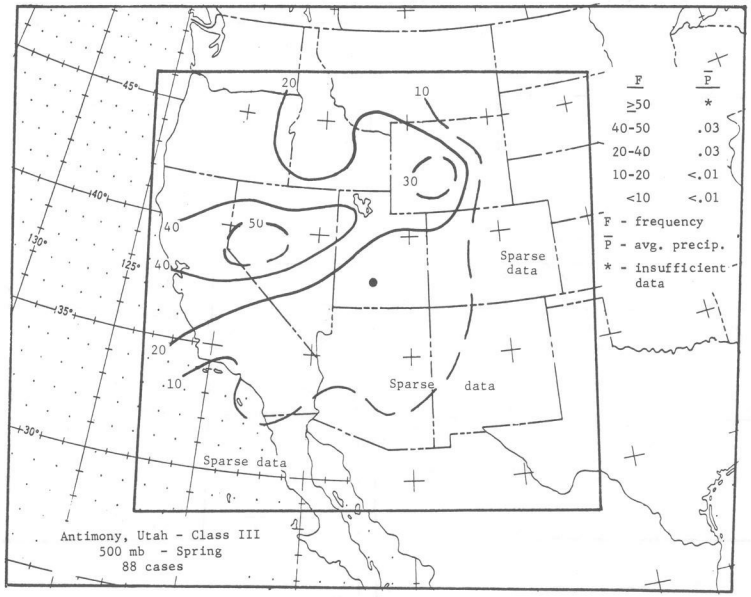



Chart 1 - IIIc

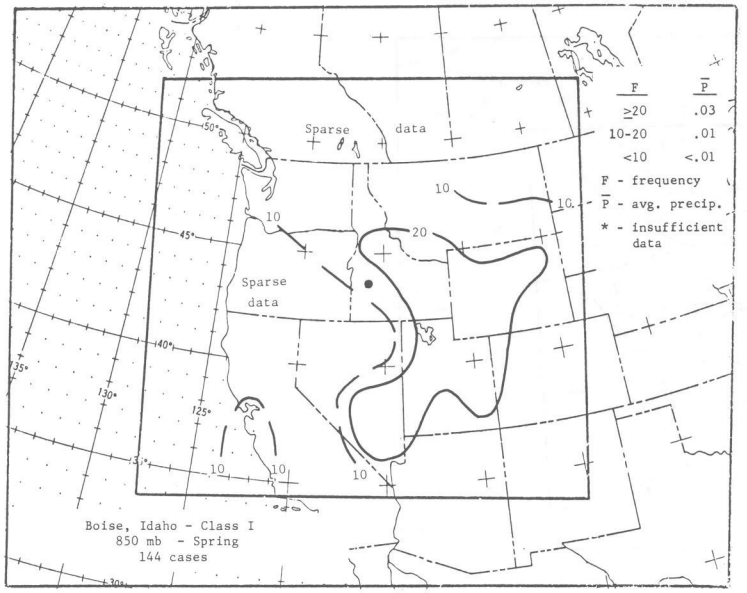



Chart 2 - Ia

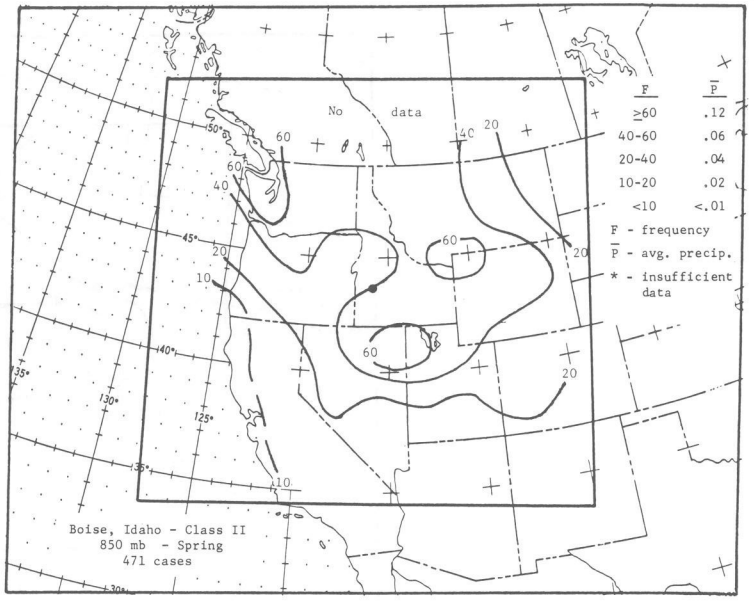



Chart 2 - IIa

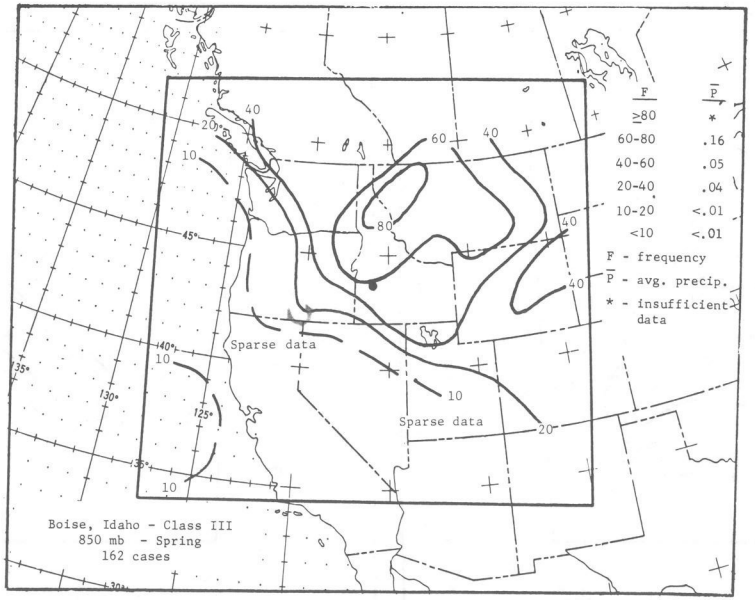



Chart 2 - IIIa

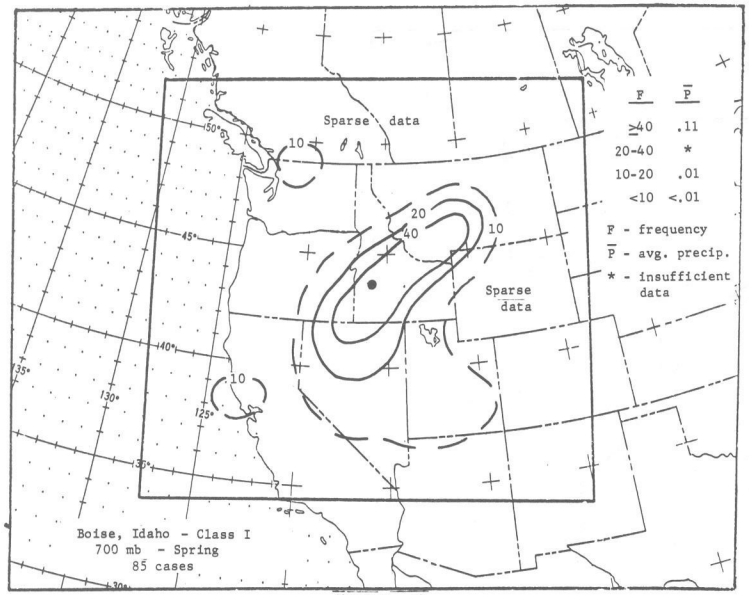



Chart 2 - Ib

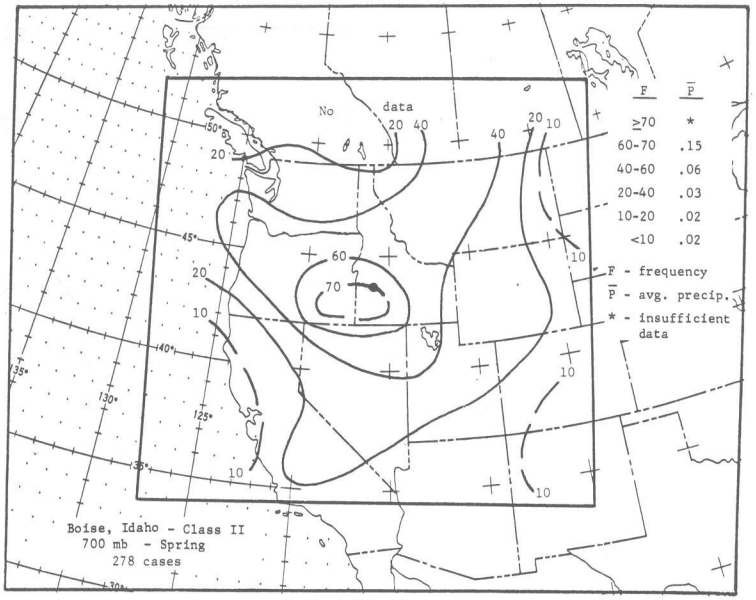



Chart 2 - IIb

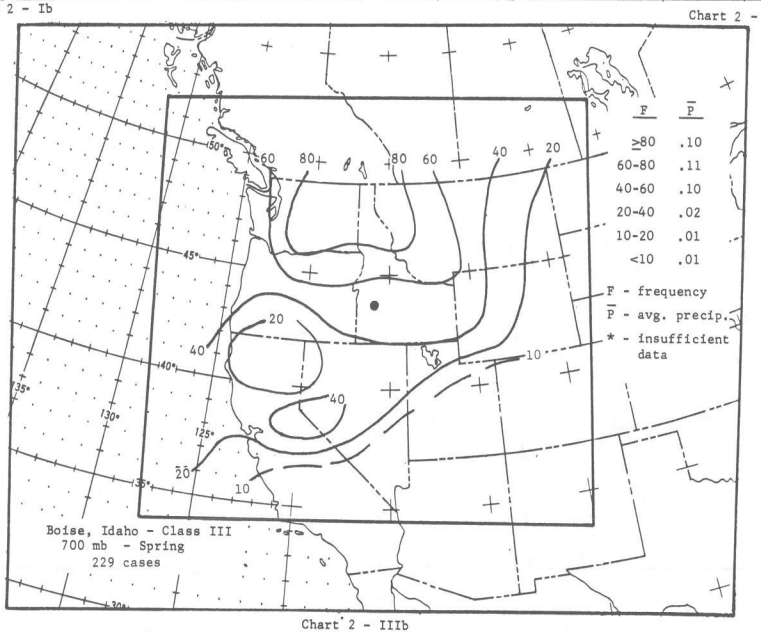



Chart 2 - IIIb

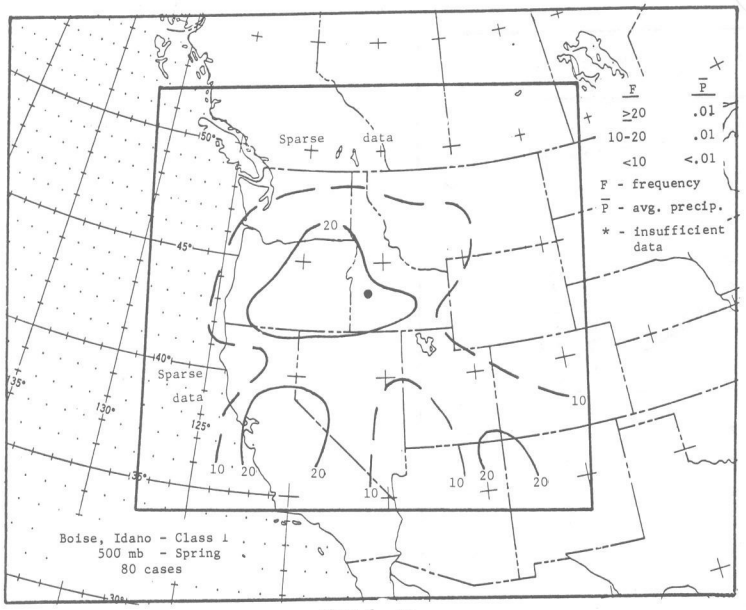



Chart 2 - Ic

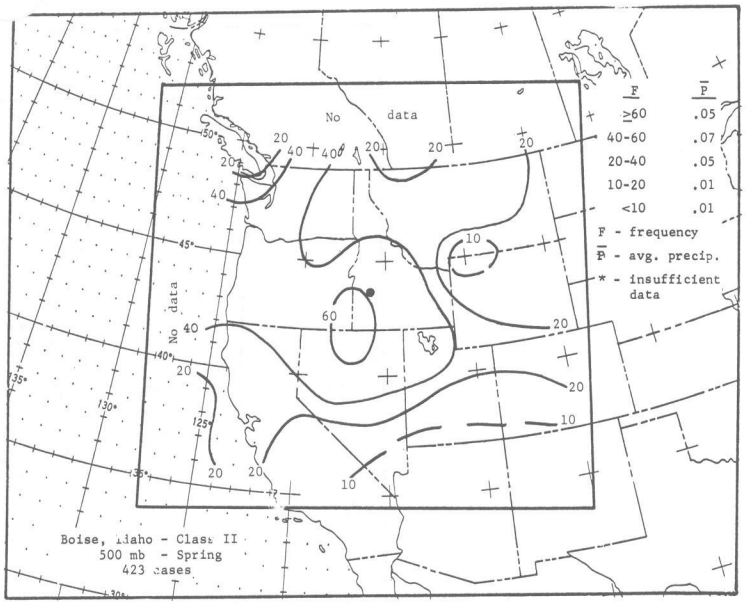



Chart 2 - IIc

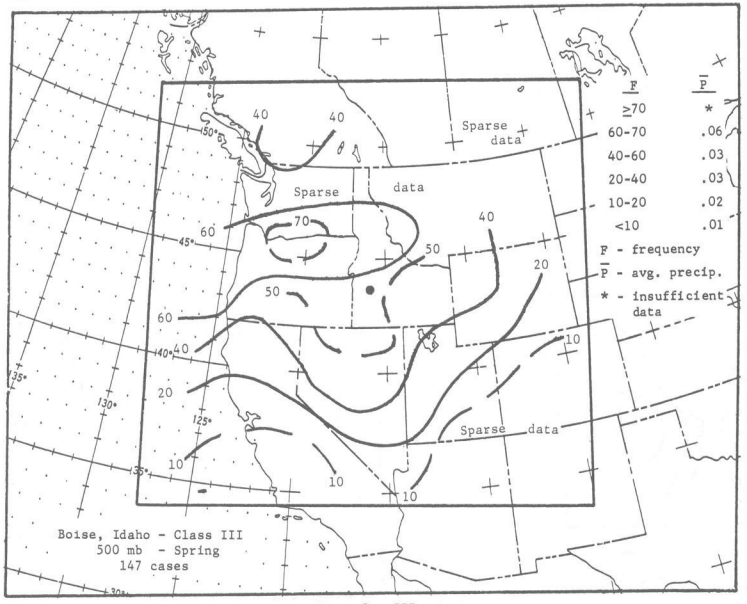



Chart 2 - IIIc

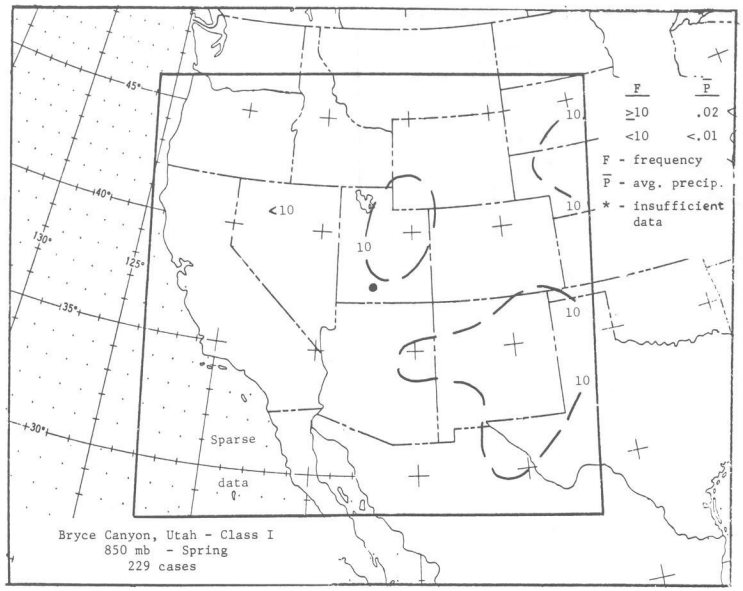



Chart 3 - Ia

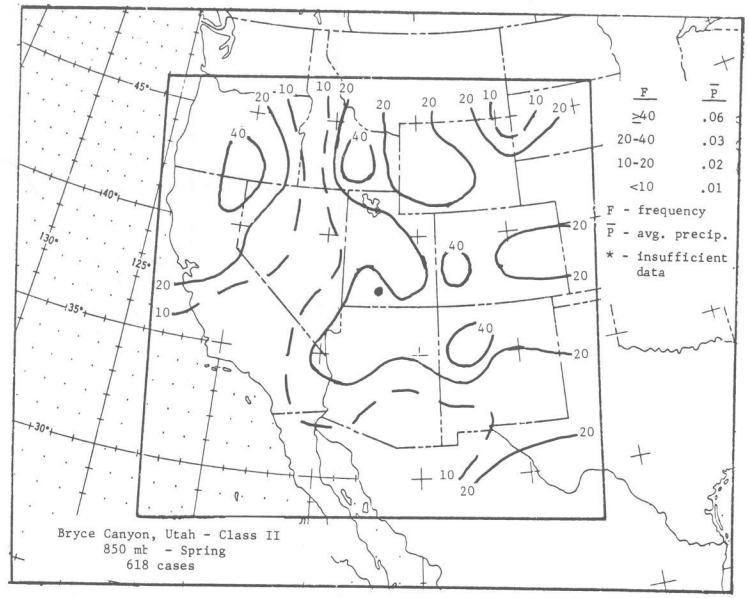
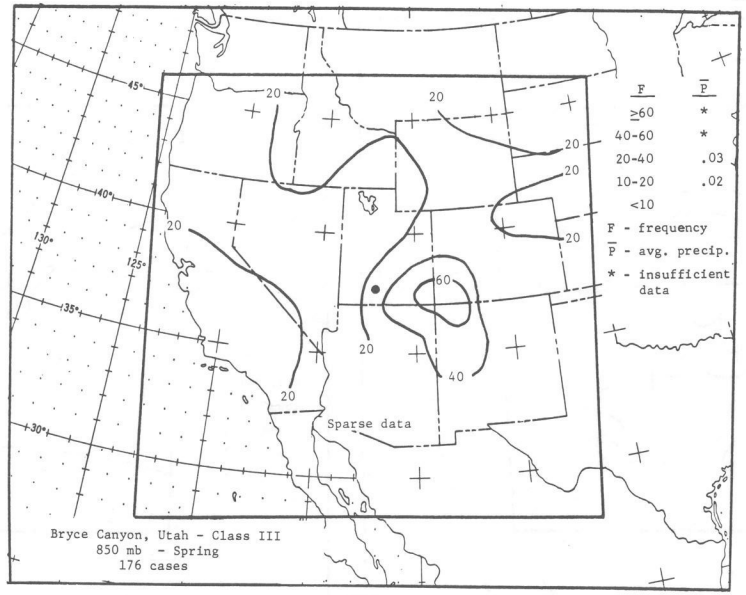



Chart 3 - IIa




- IIIa

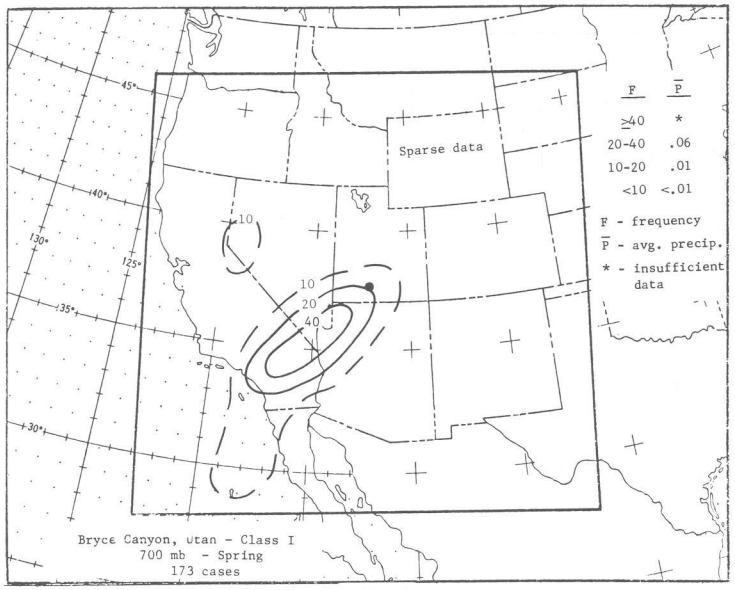



Chart 3 - Ib

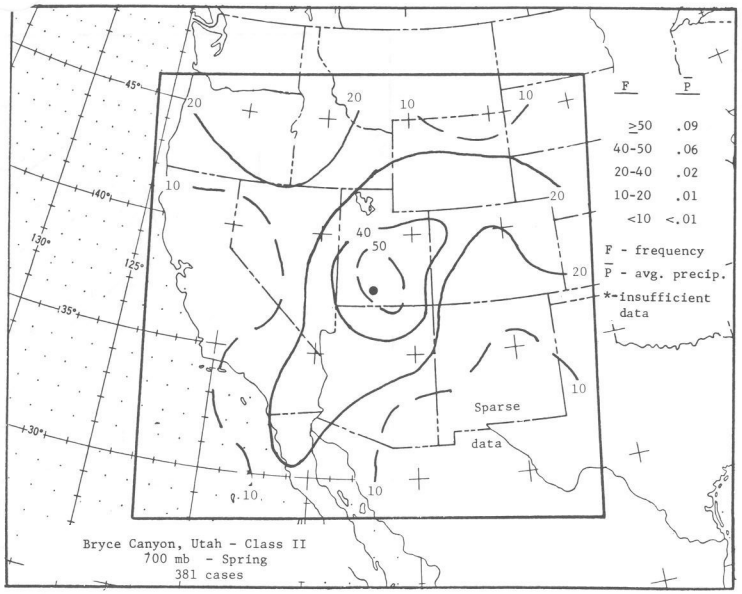



Chart 3 - IIb

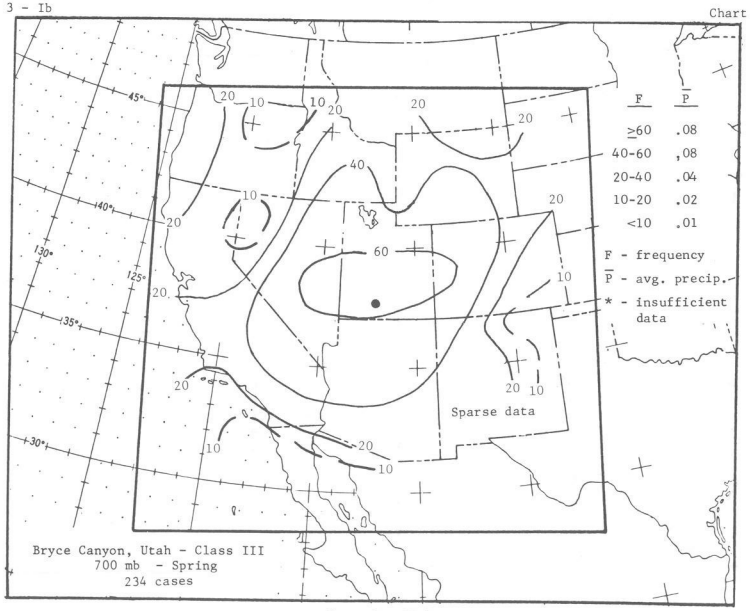



Chart 3 - IIIb

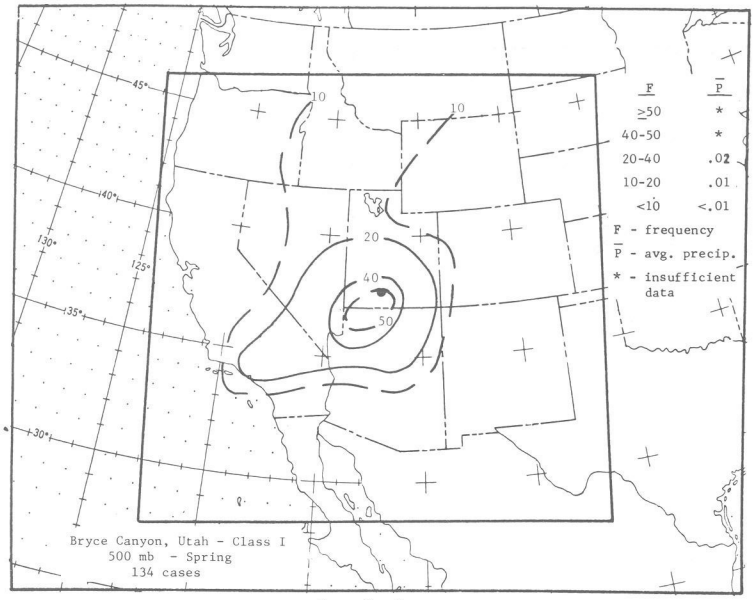



Chart 3 - Ic

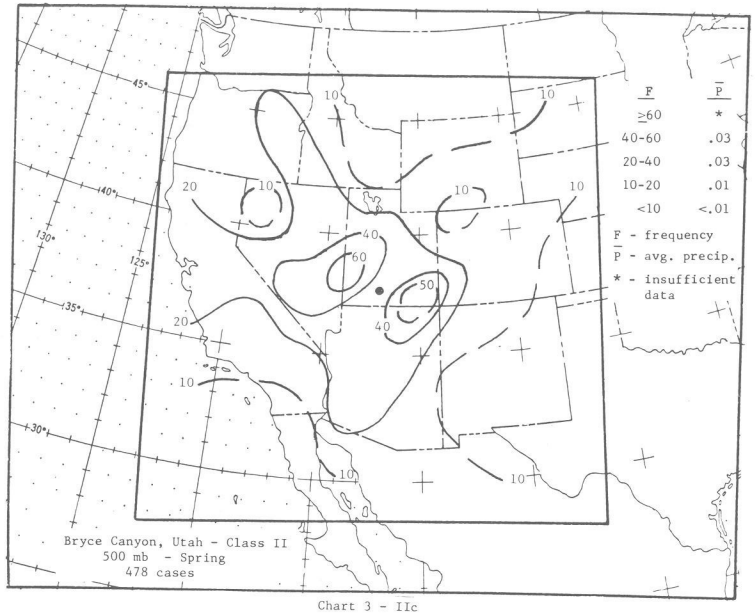



Chart 3 - IIc

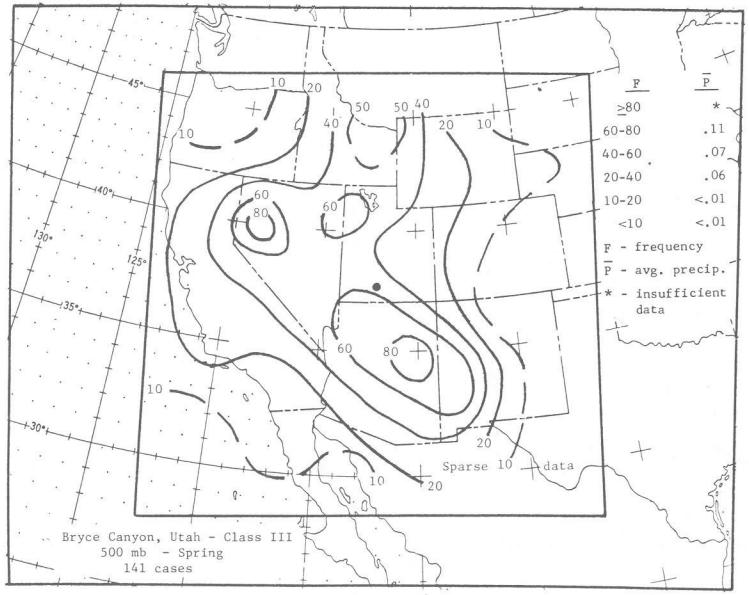



Chart 3 - IIIc

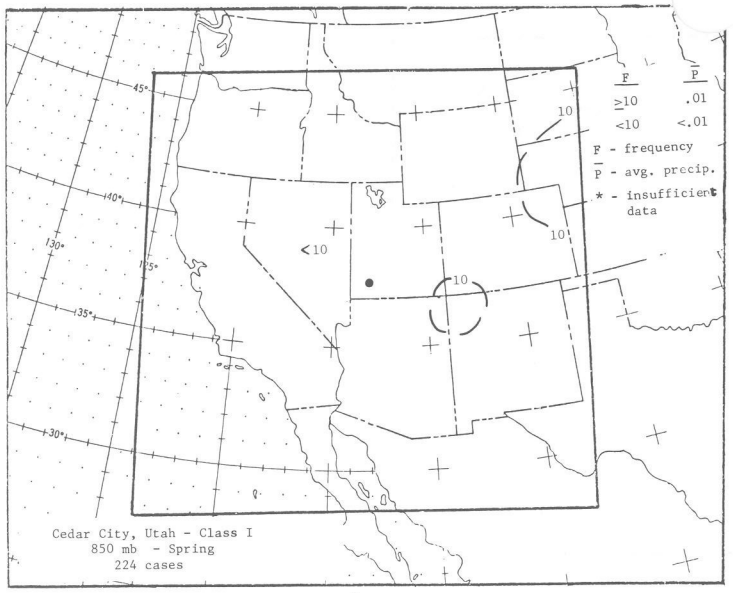



Chart 4 - Ia

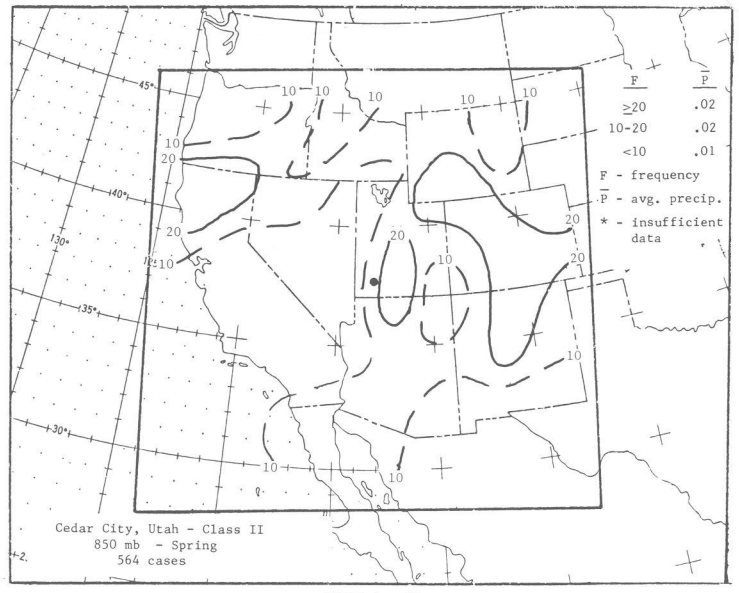



Chart 4 - IIa

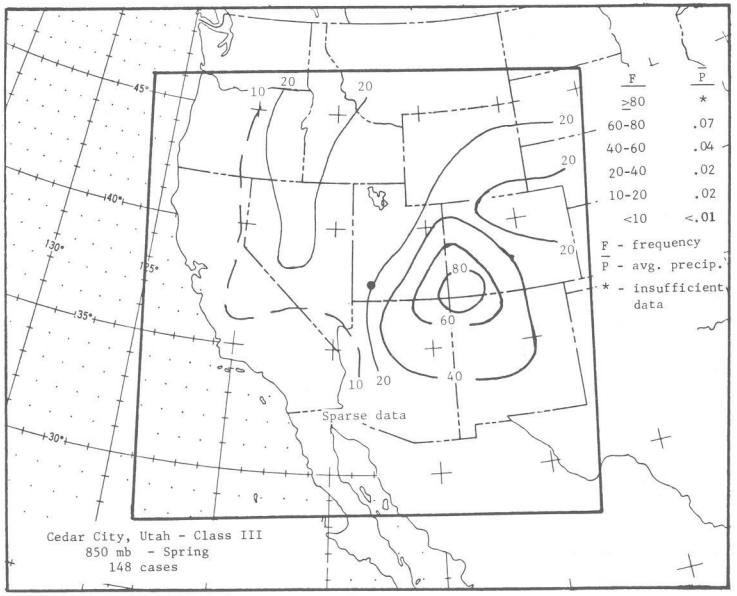



Chart 4 - IIIa

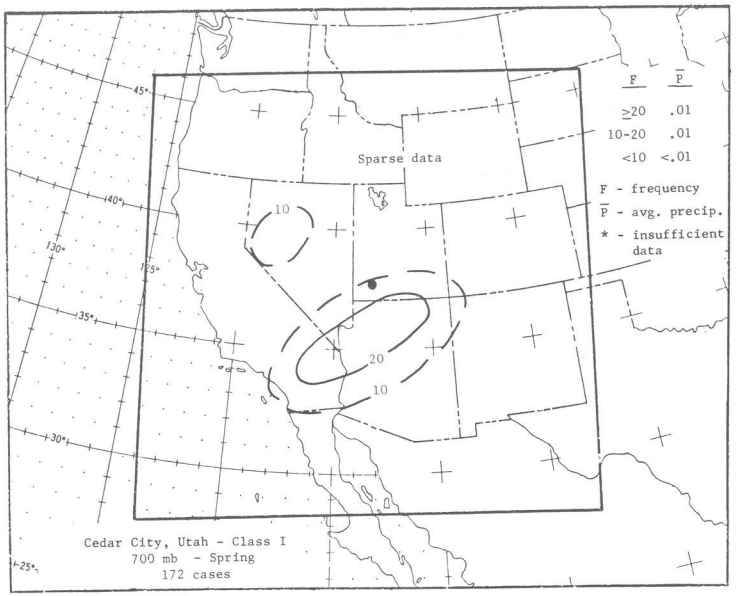



Chart 4 - Ib

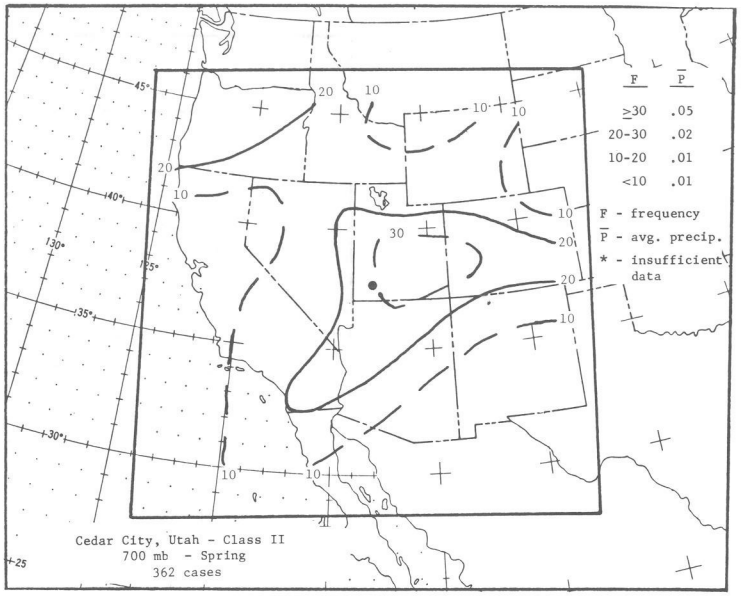
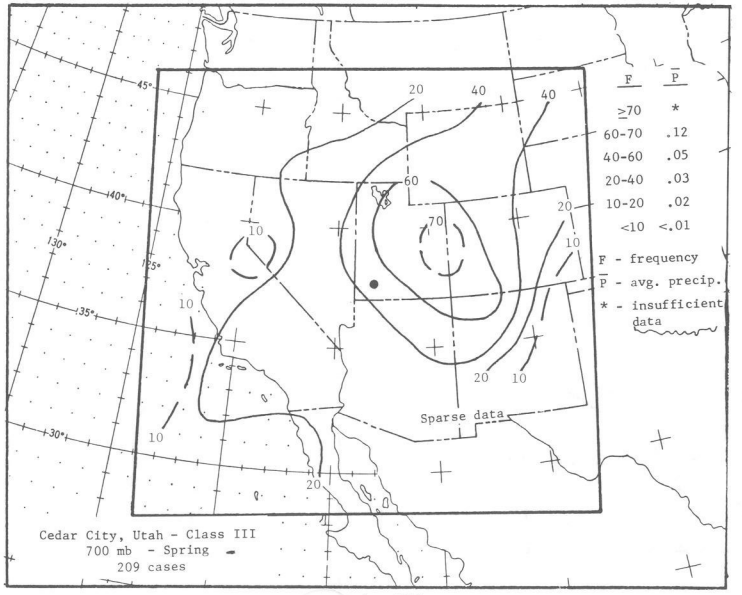



Chart 4 - IIb




4 - IIIb

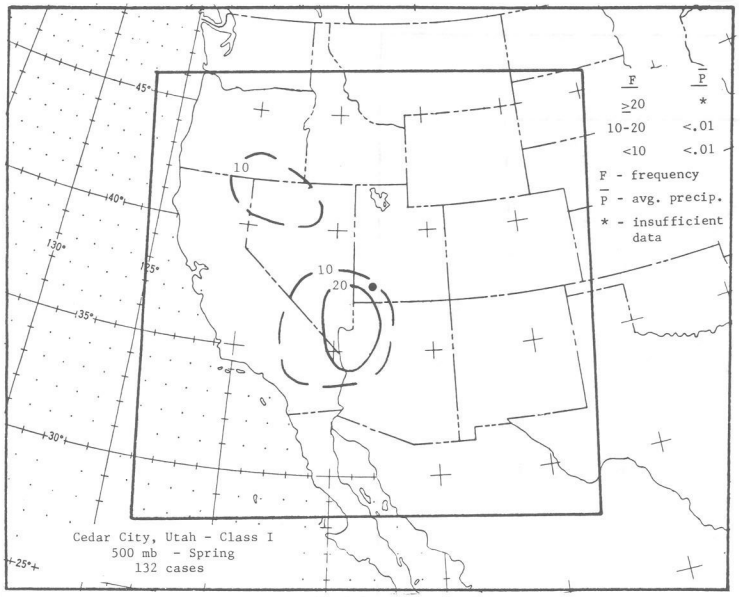



Chart 4 - Ic

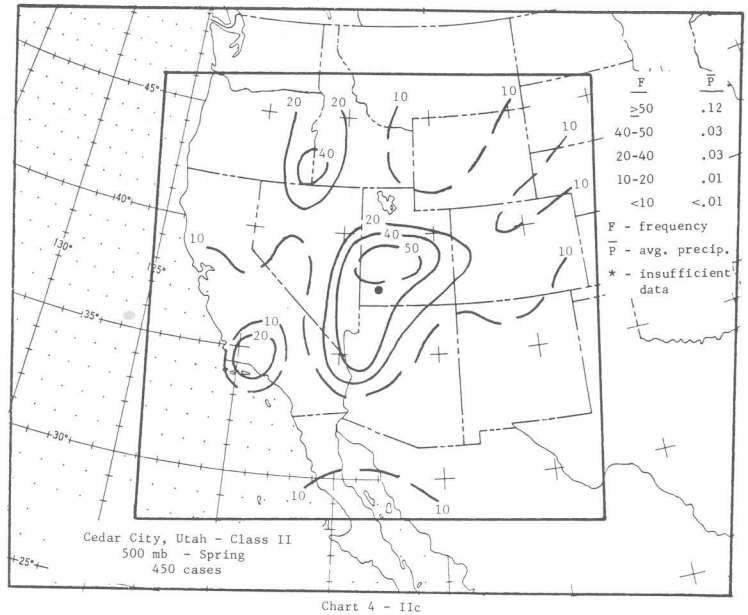



Chart 4 - IIc

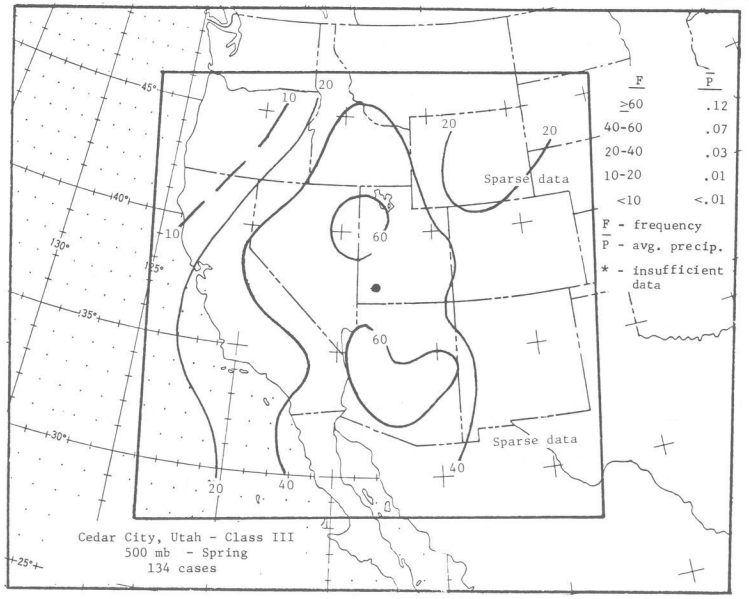



Chart 4 - IIIc

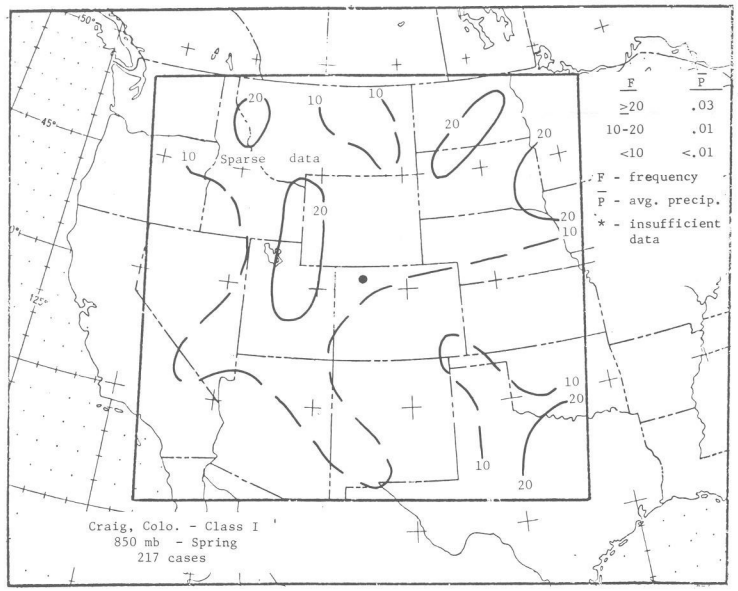



Chart 5 - Ia

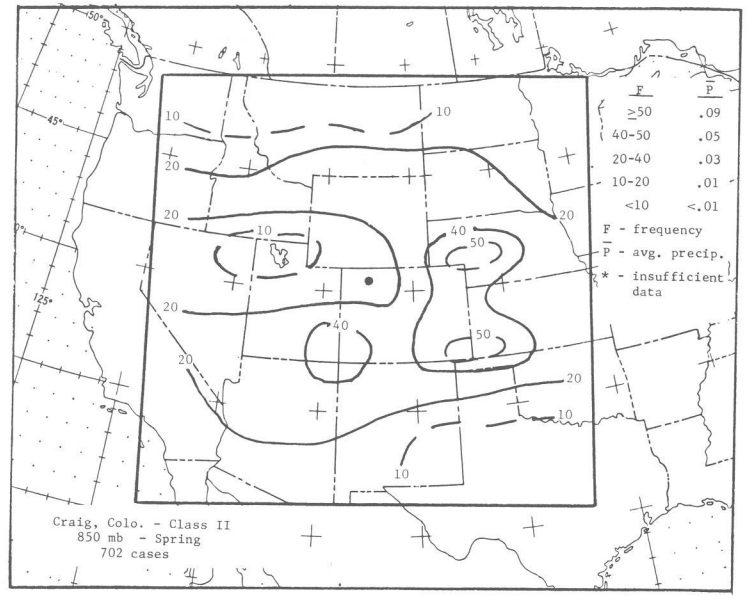



Chart 5 - IIa

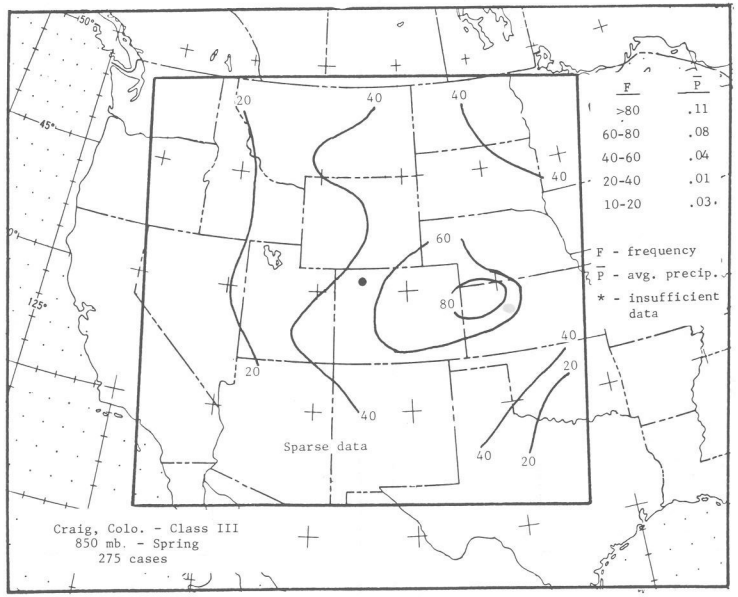



Chart 5 - IIIa

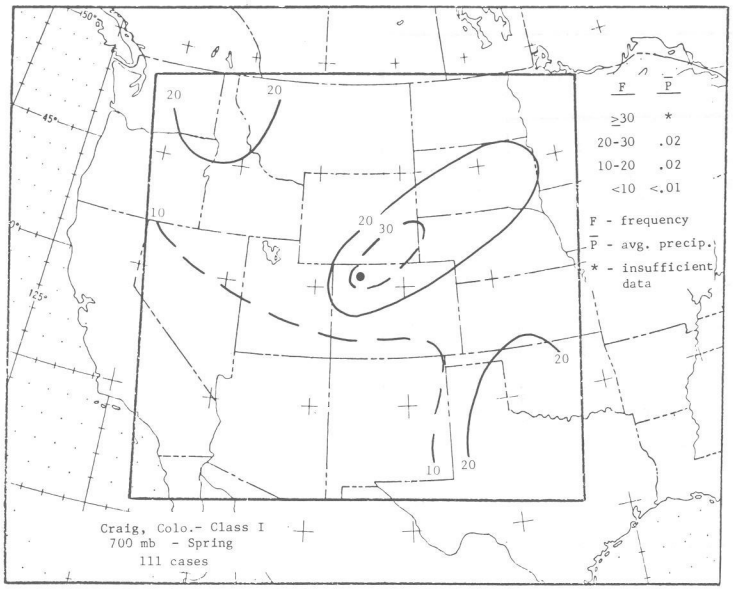



Chart 5 - Ib

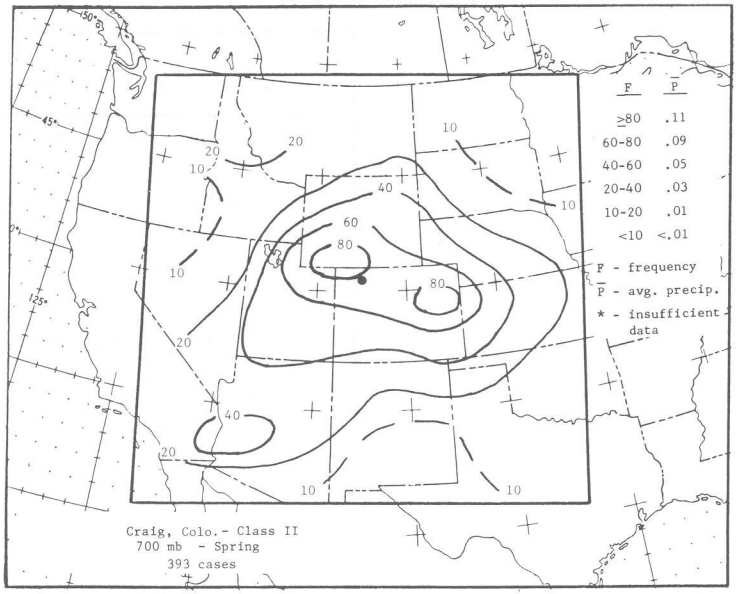



Chart 5 - IIb

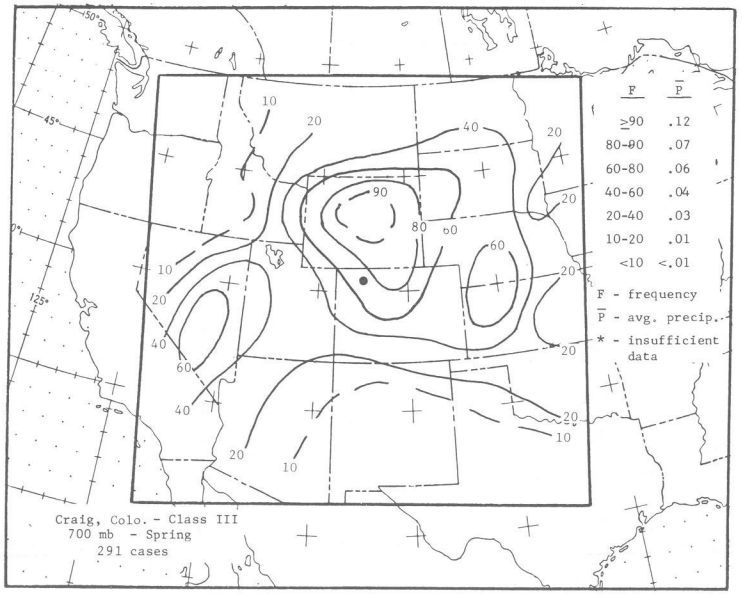



Chart 5 - IIIb

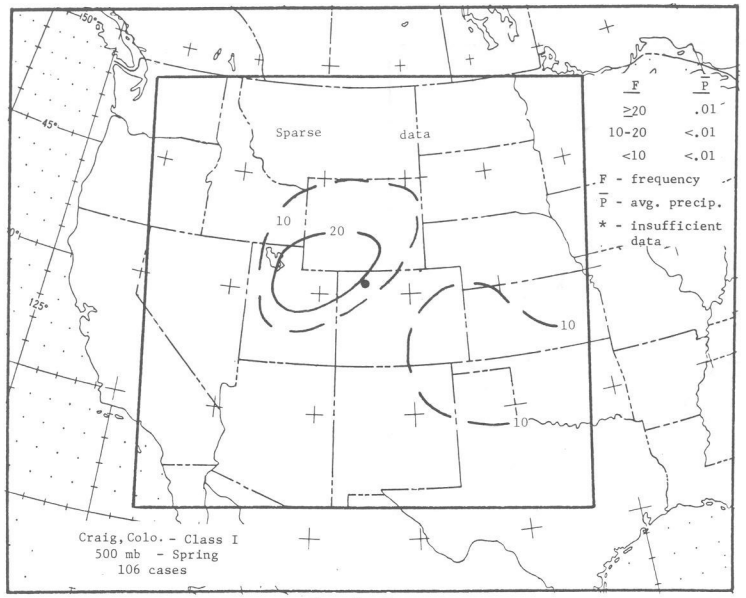



Chart 5 - Ic

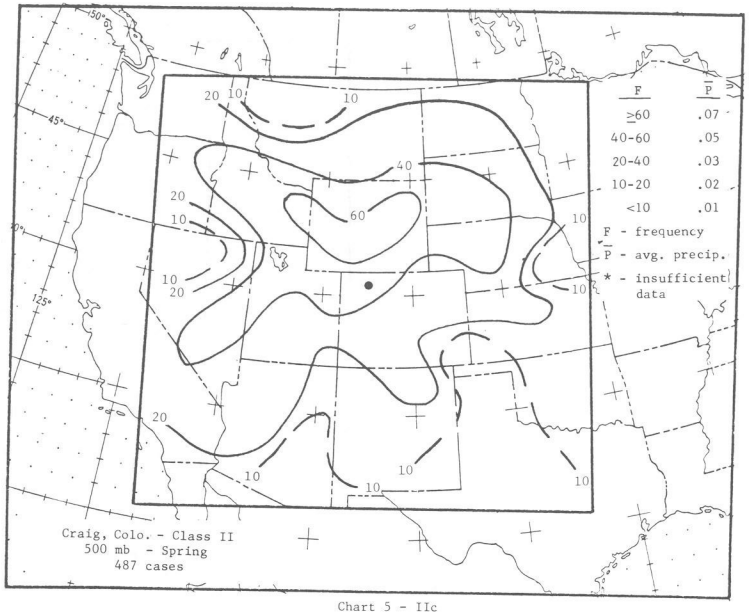



Chart 5 - IIc

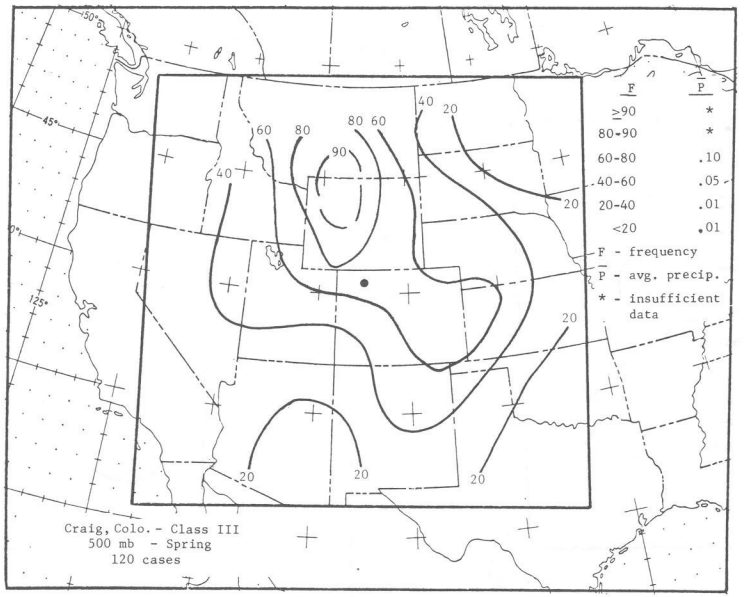



Chart 5 - IIIc

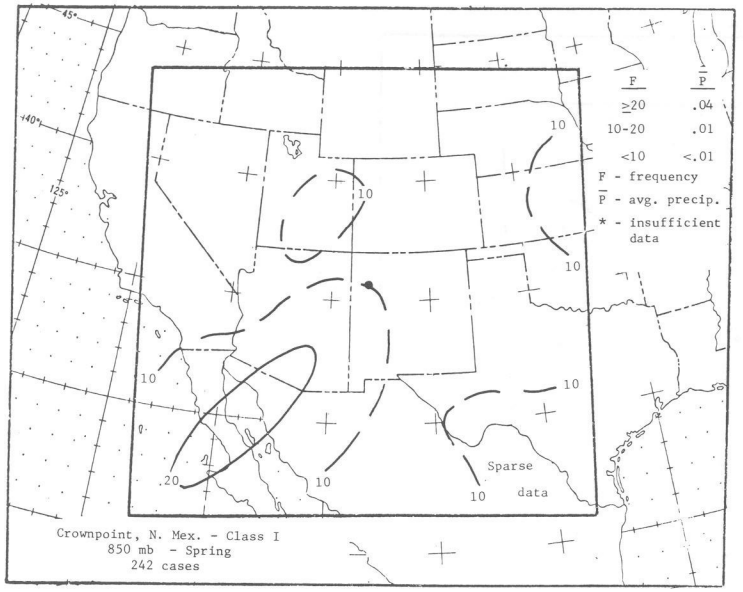



Chart 6 - Ia

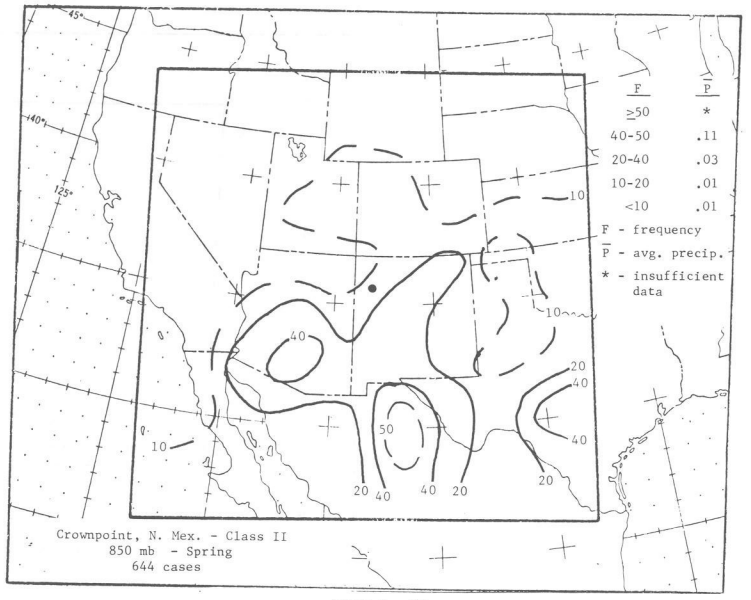



Chart 6 - IIa

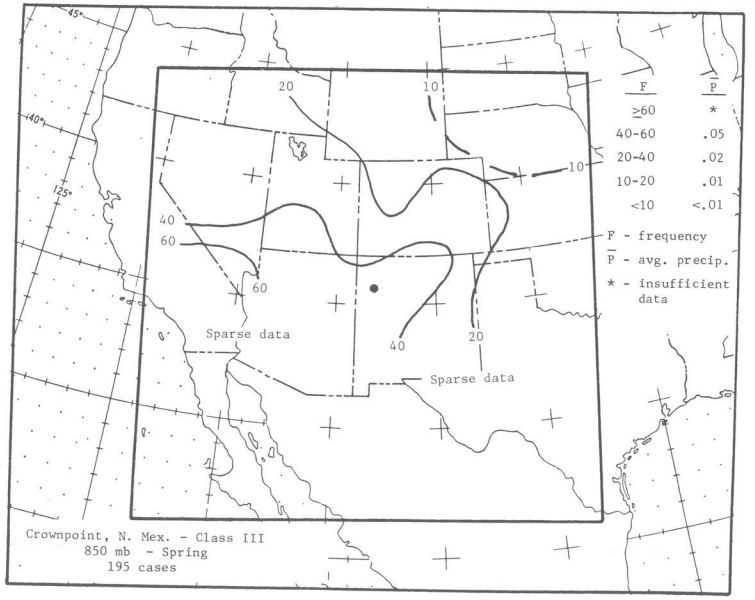



Chart 6 - IIIa

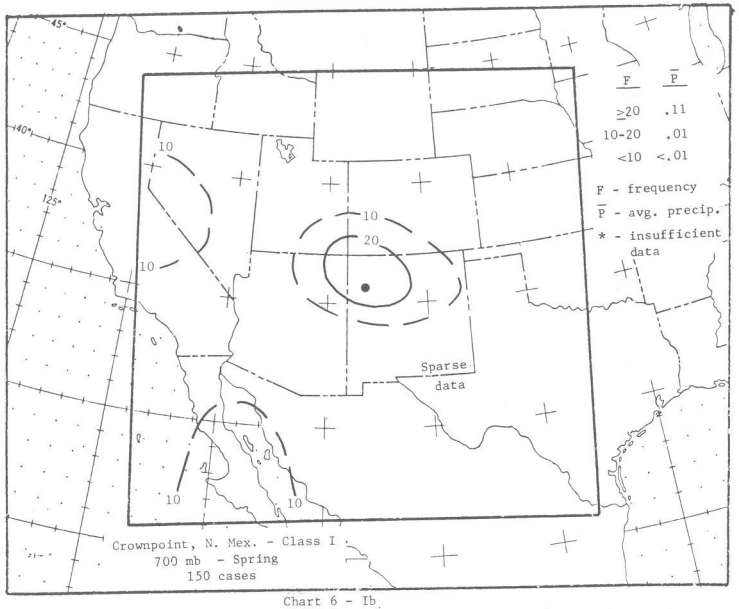



Chart 6 - Ib

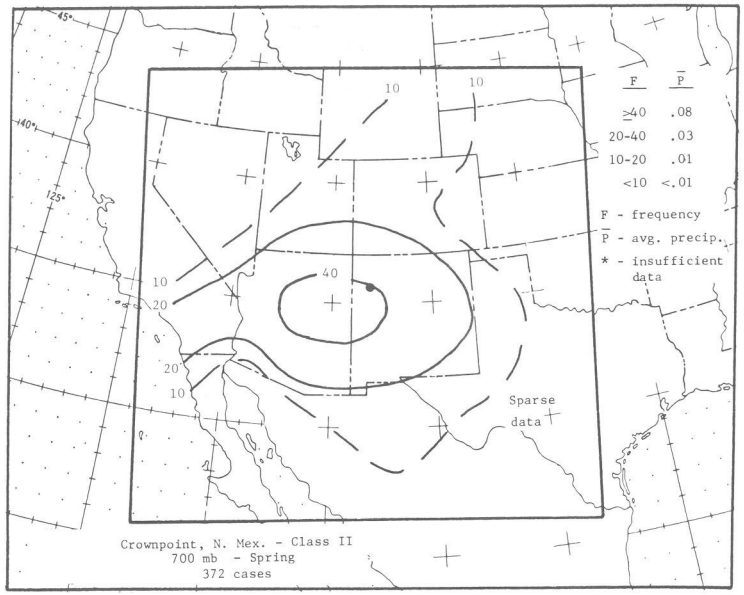



Chart 6 - IIb

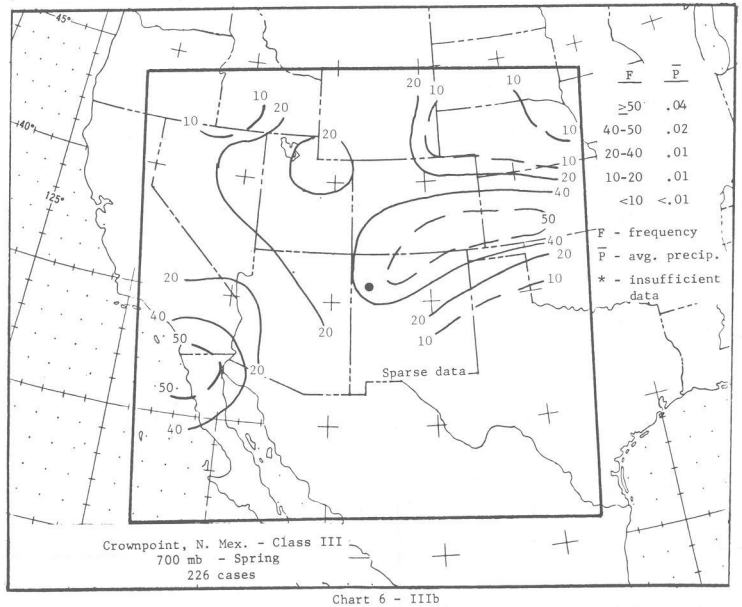



Chart 6 - IIIb

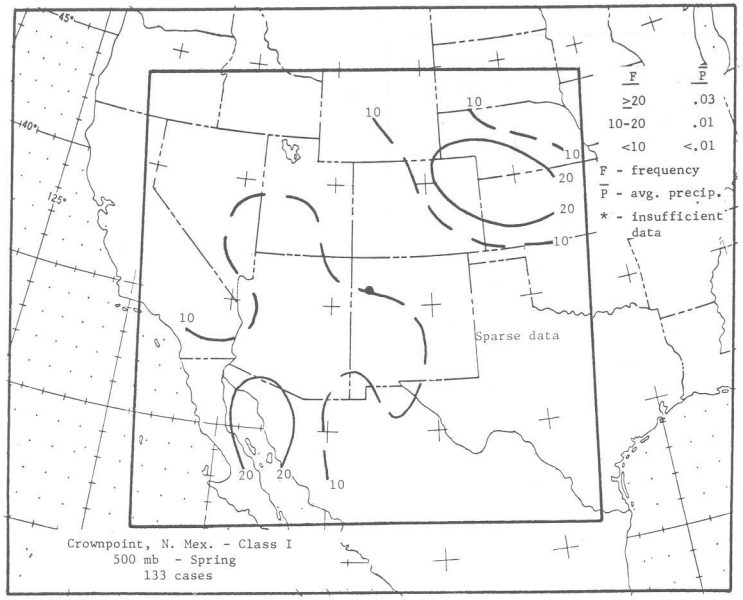



Chart 6 - Ic

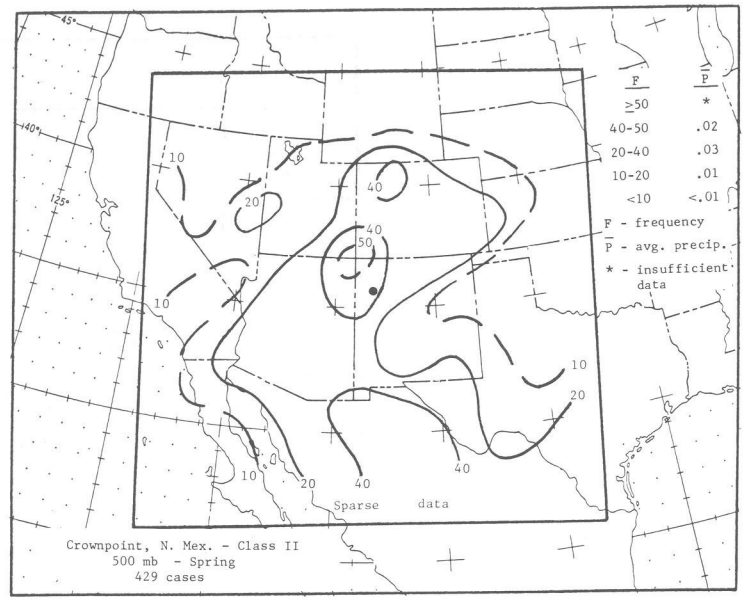



Chart 6 - IIc

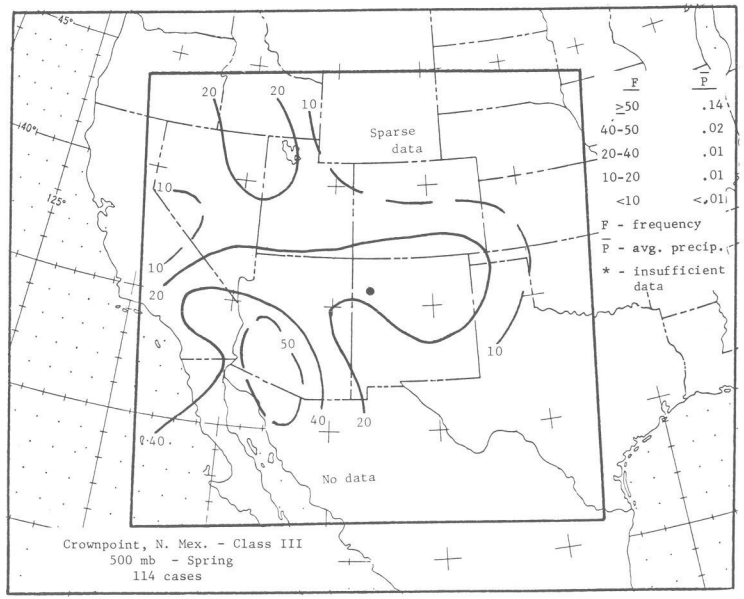



Chart 6 - IIIc

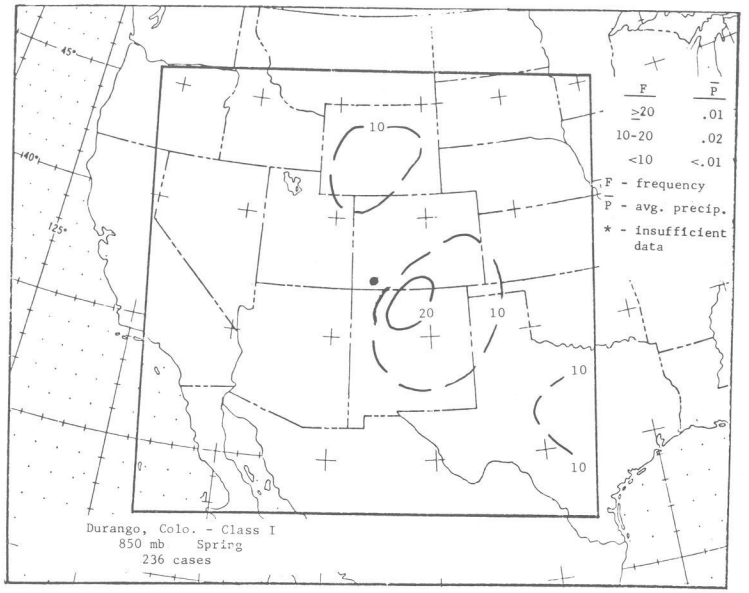



Chart 7 - Ia

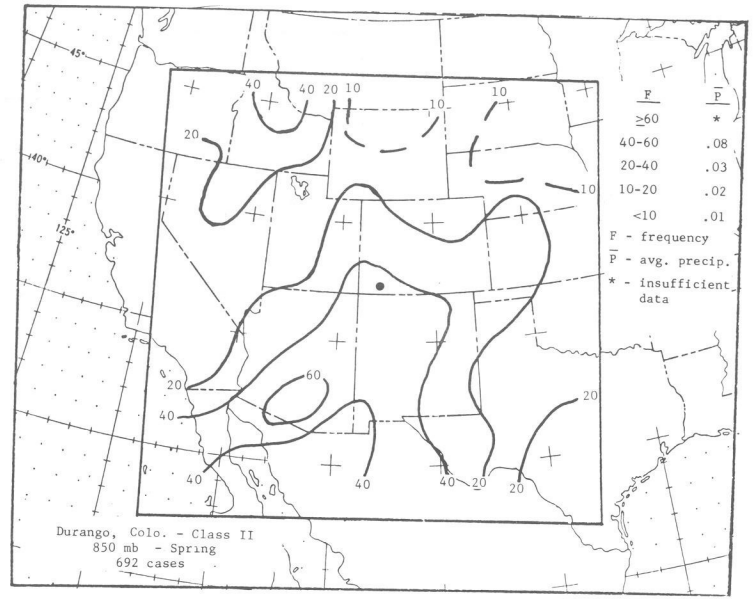



Chart 7 - IIa

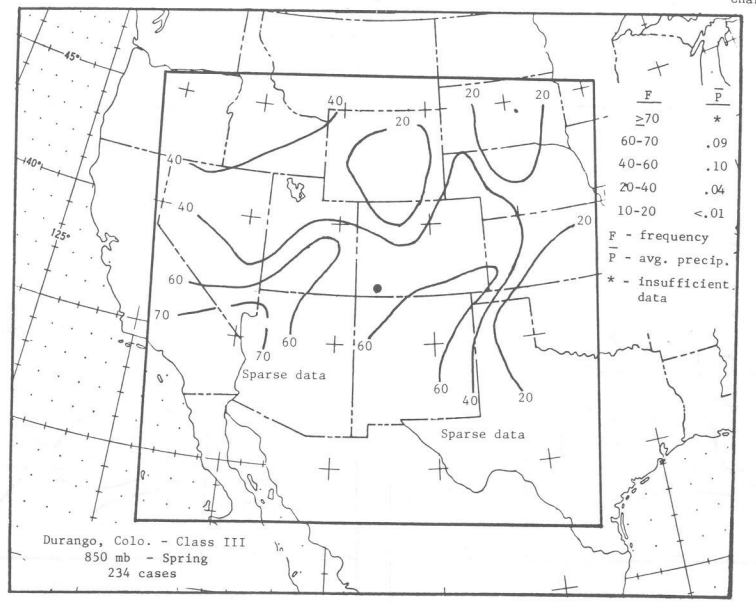



Chart 7 - IIIa

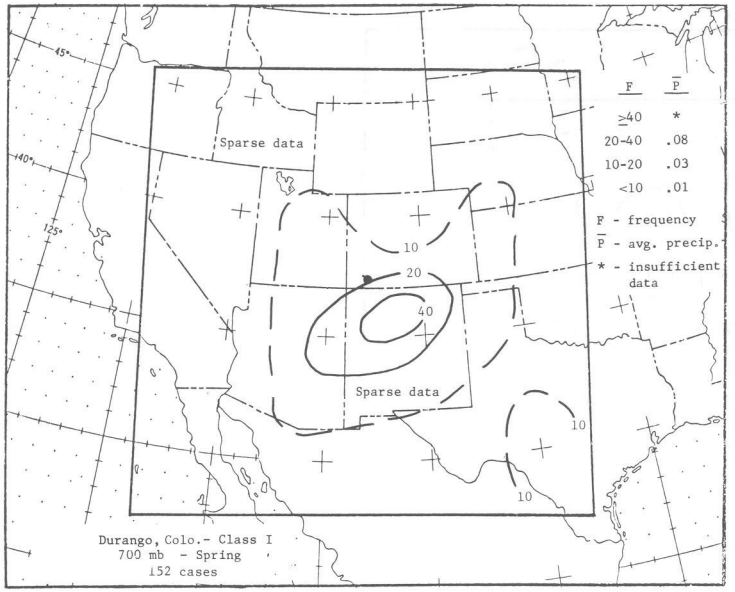



Chart 7 - Ib

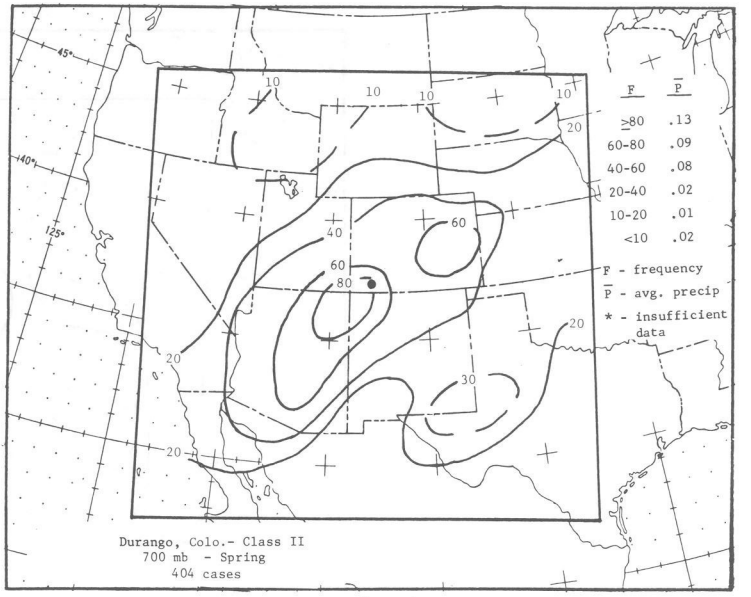



Chart 7 - IIb

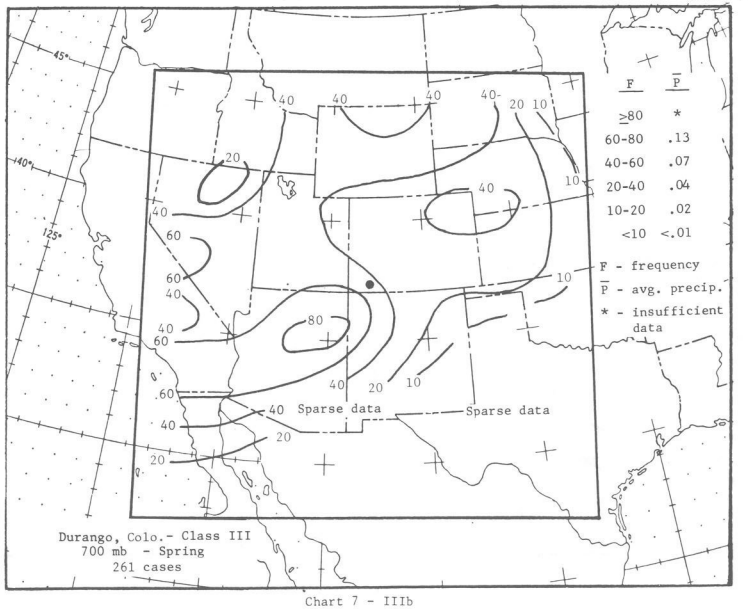



Chart 7 - IIIb

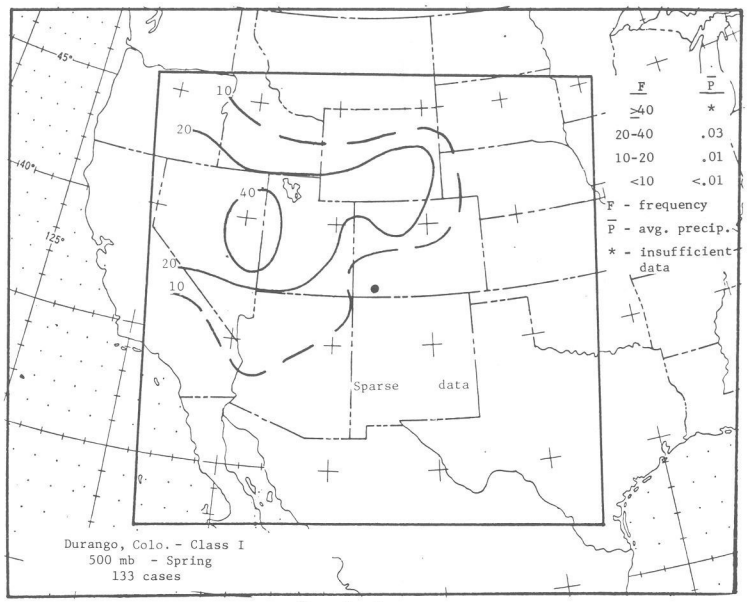



Chart 7 - Ic

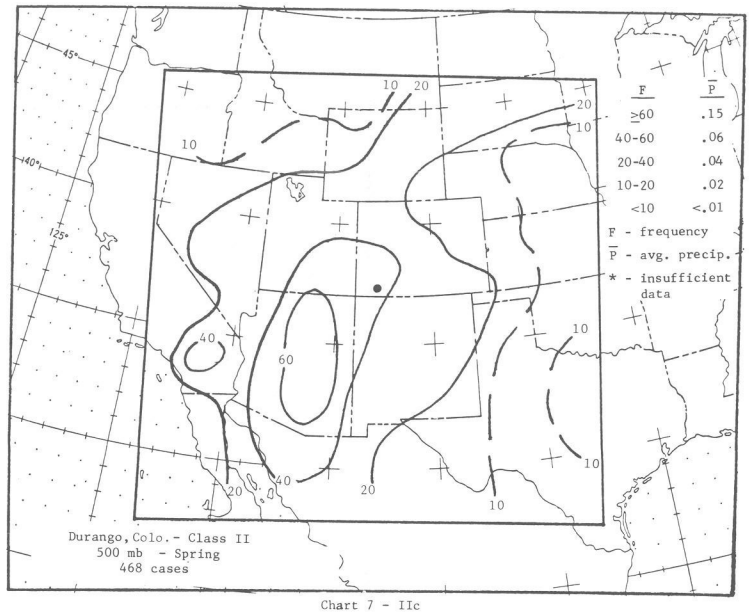



Chart 7 - IIc

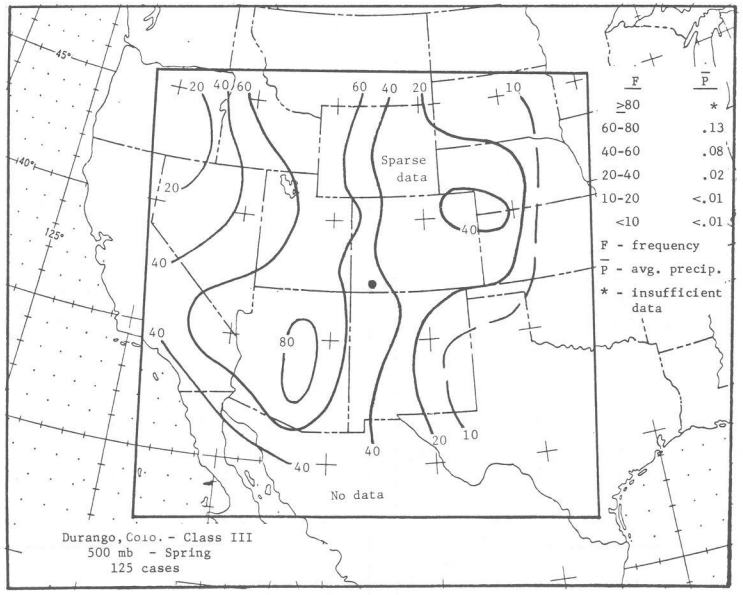



Chart 7 - IIIc

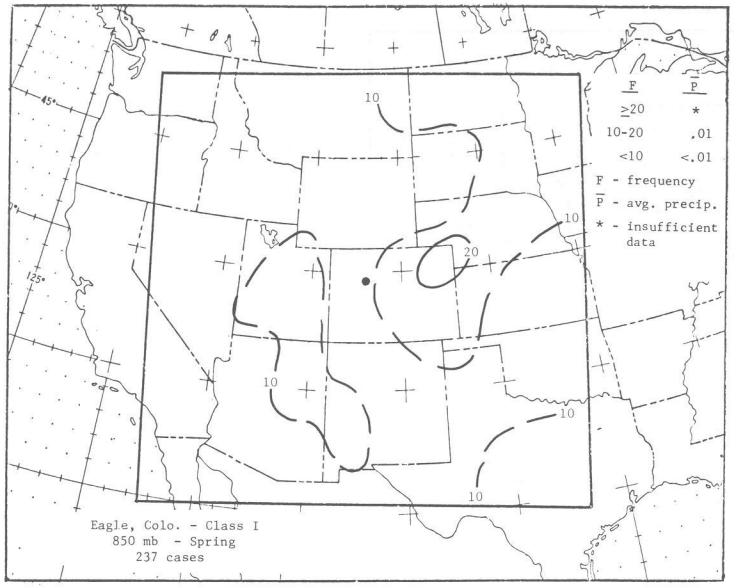



Chart 8 - Ia

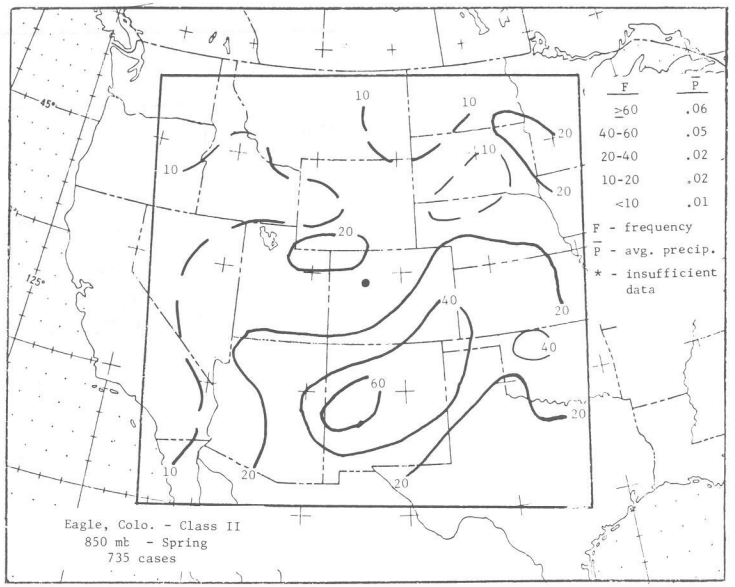



Chart 8 - IIa

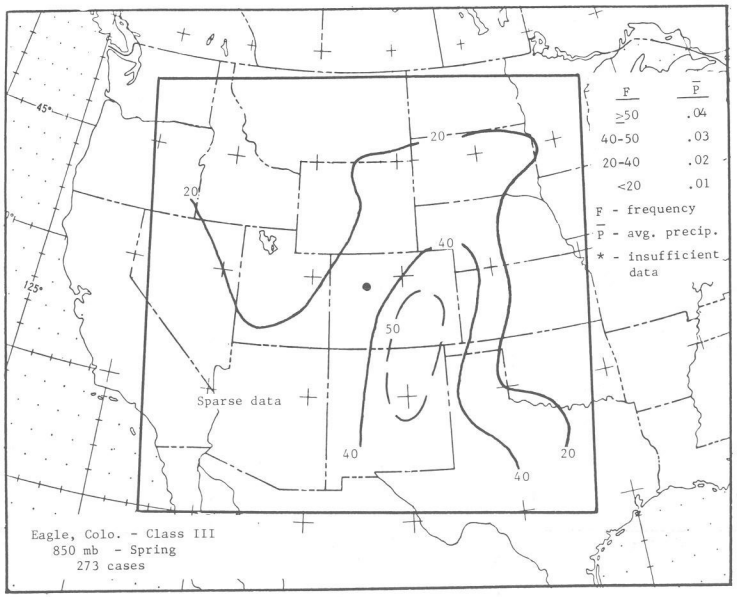



Chart 8 - IIIa

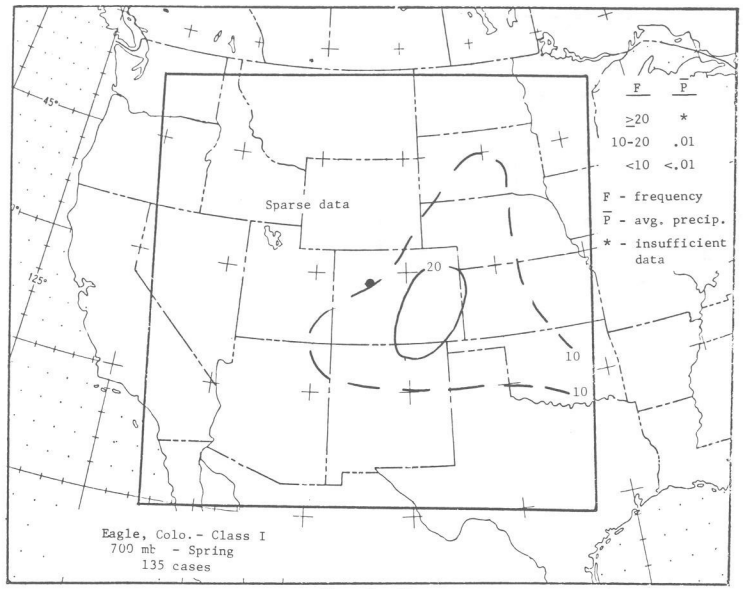



Chart 8 - Ib

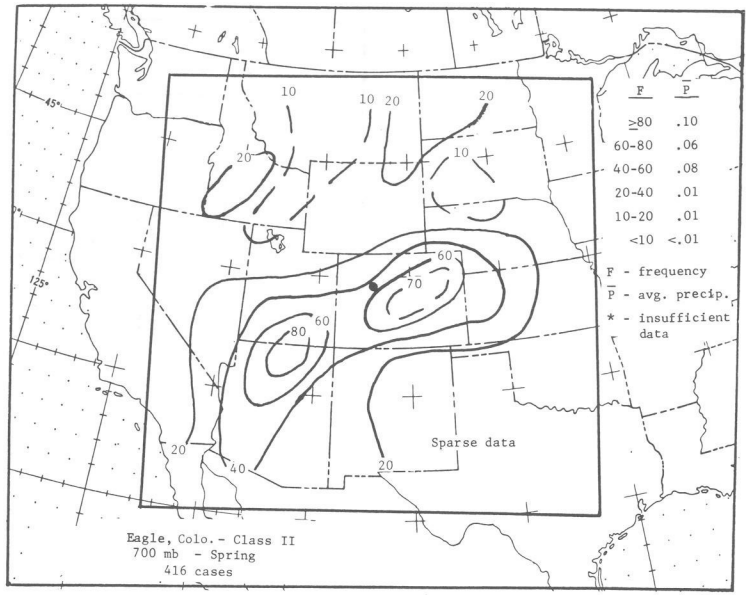



Chart 8 - IIb

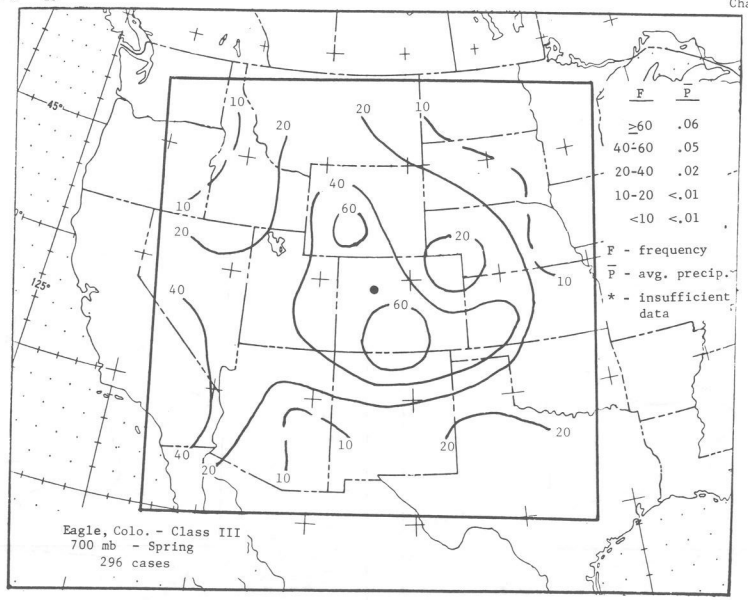



Chart 8 - IIIb

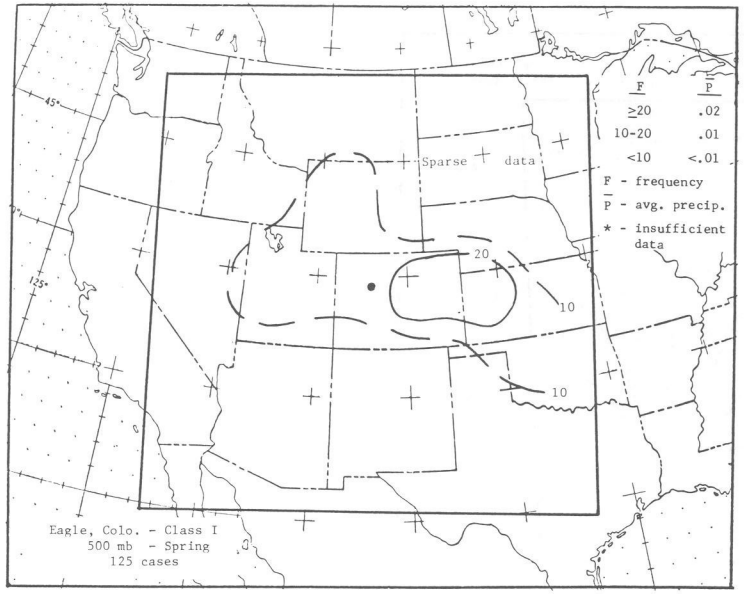



Chart 8 - Ic

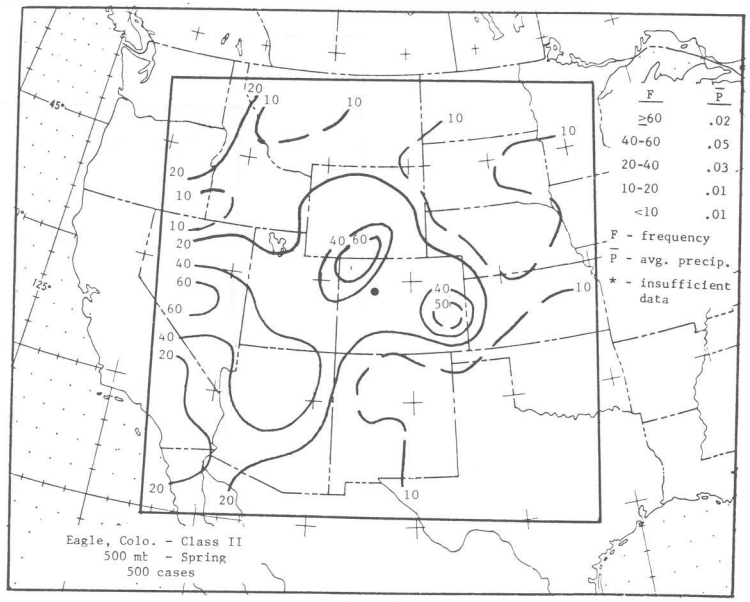



Chart 8 - IIc

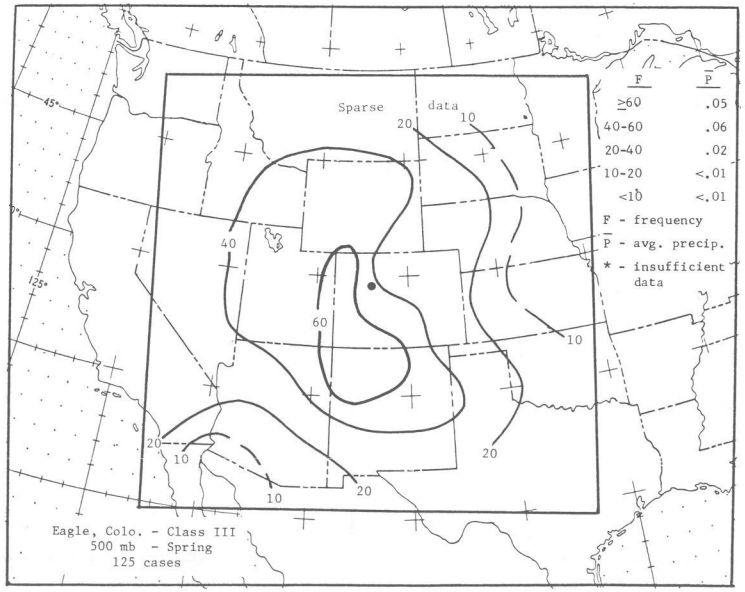



Chart 8 - IIIc

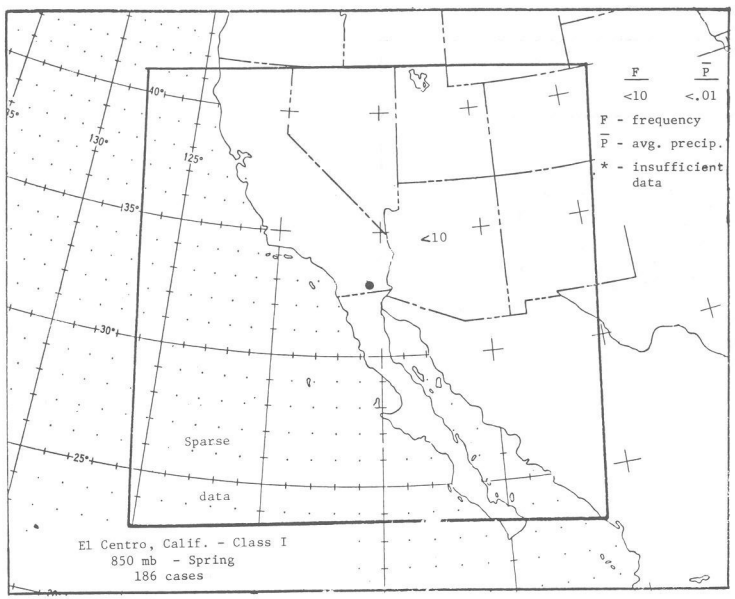



Chart 9 - Ia

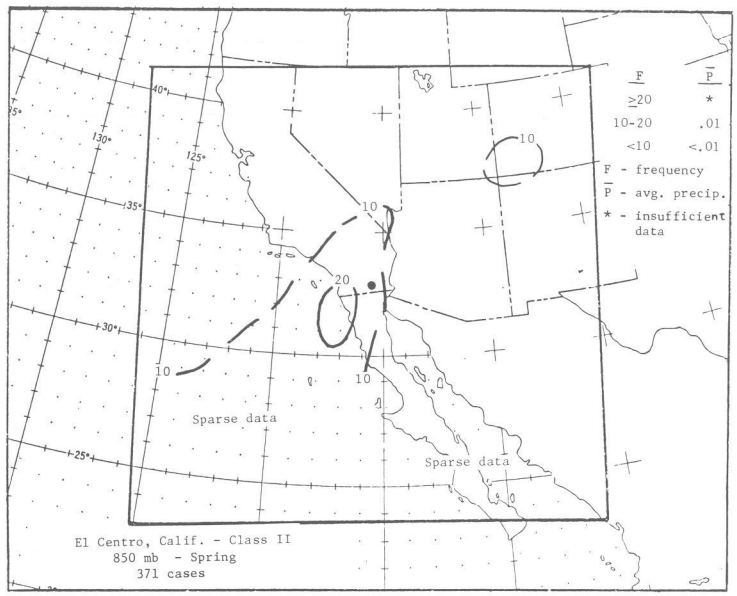



Chart 9 - IIa

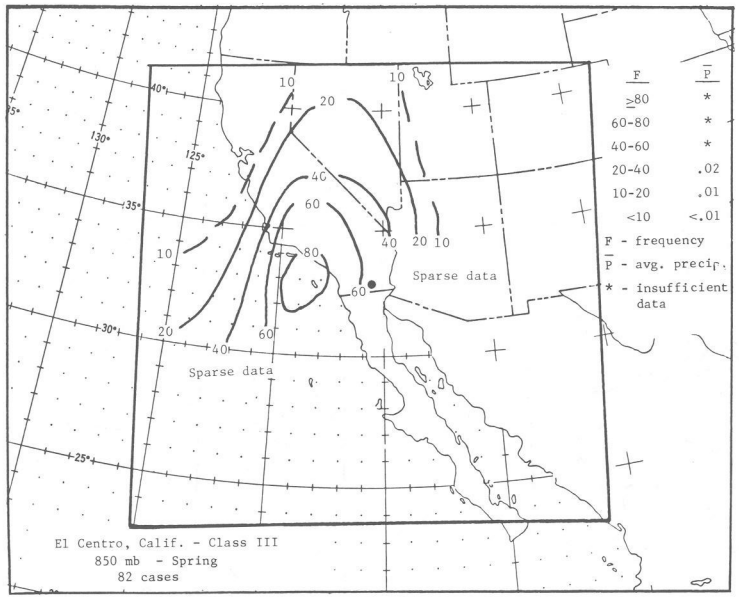



Chart 9 - IIIa

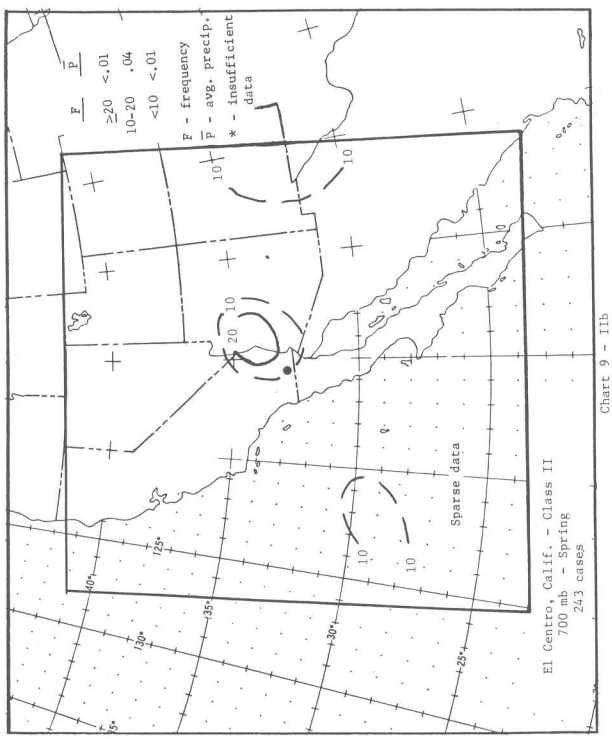



Chart 9 - IIb

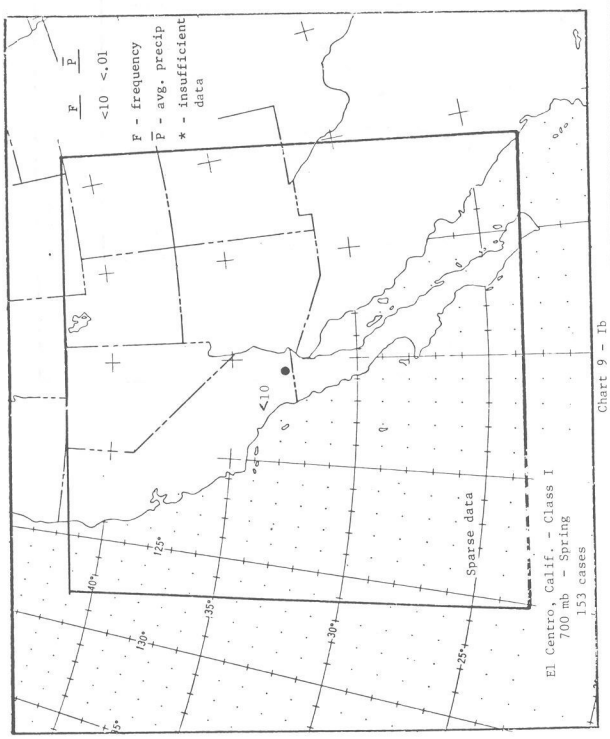



Chart 9 - Ib

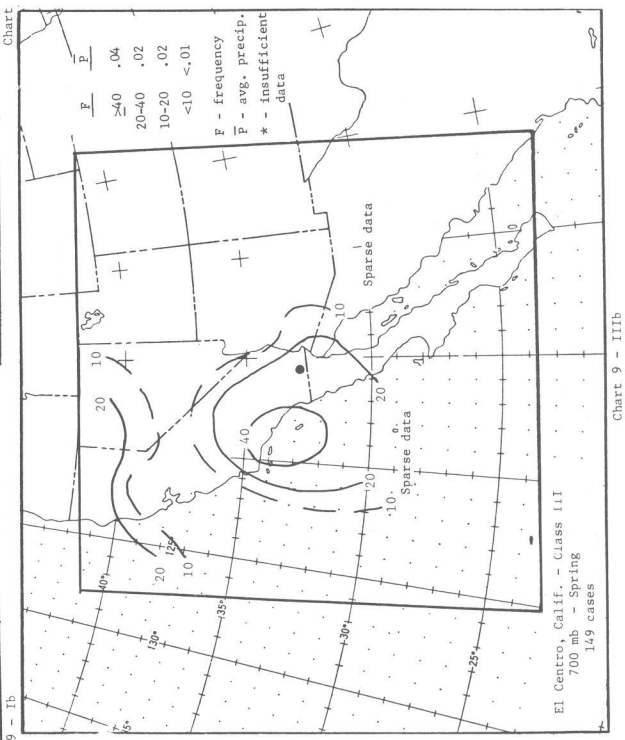



Chart 9 - IIIb

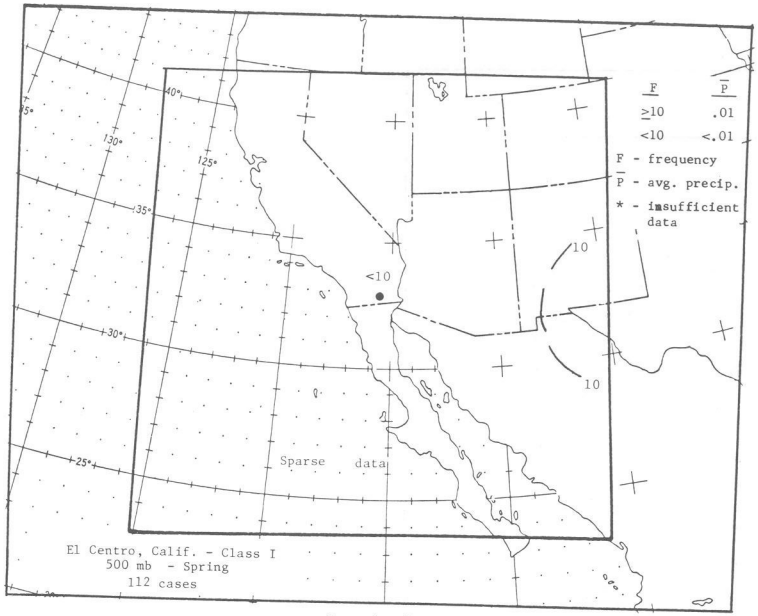



Chart 9 - Ic

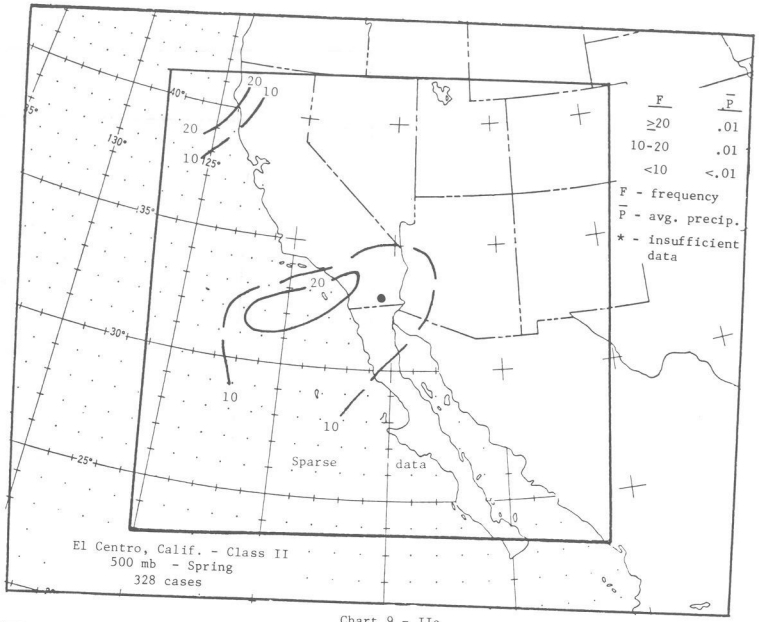



Chart 9 - IIc

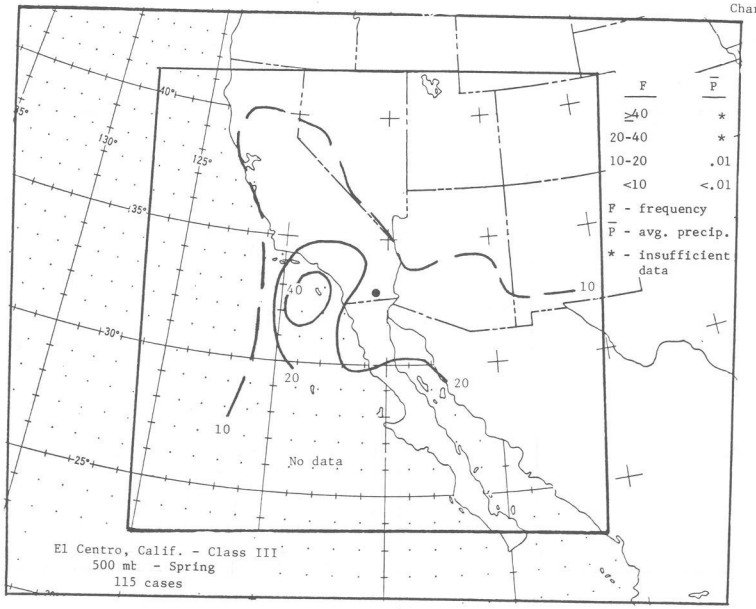



Chart 9 - IIIc

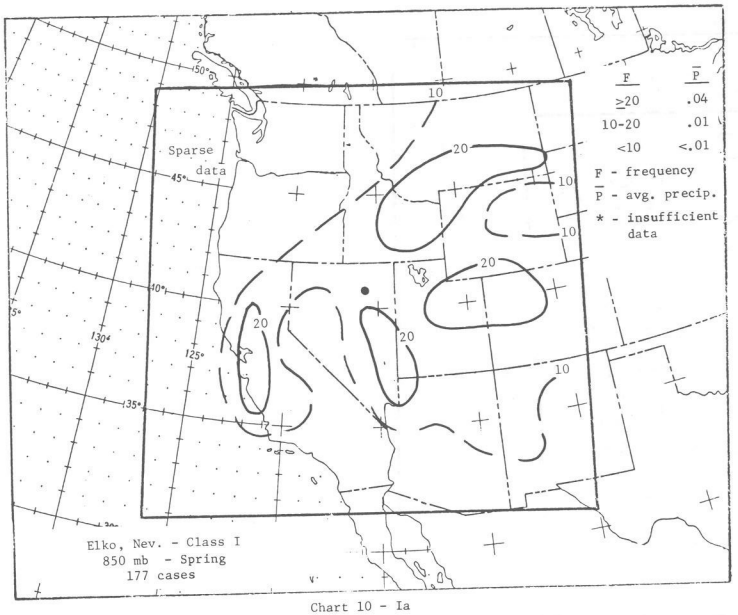



Chart 10 - Ia

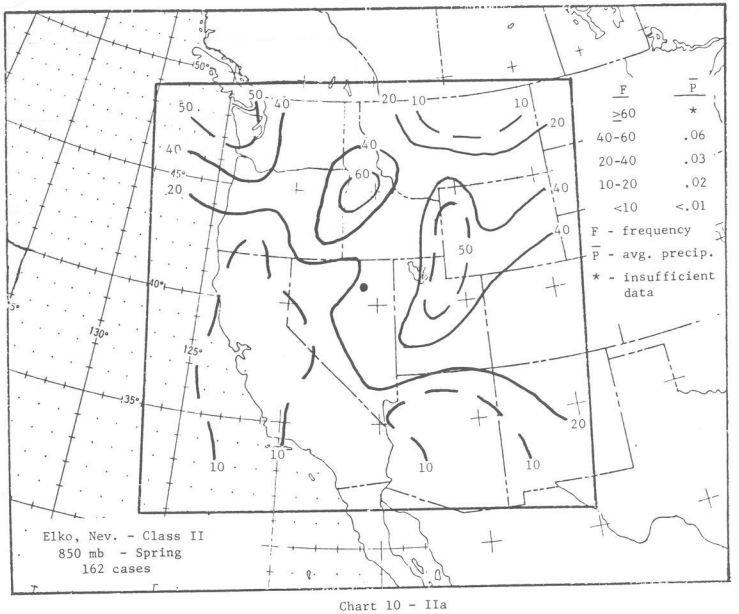



Chart 10 - IIa

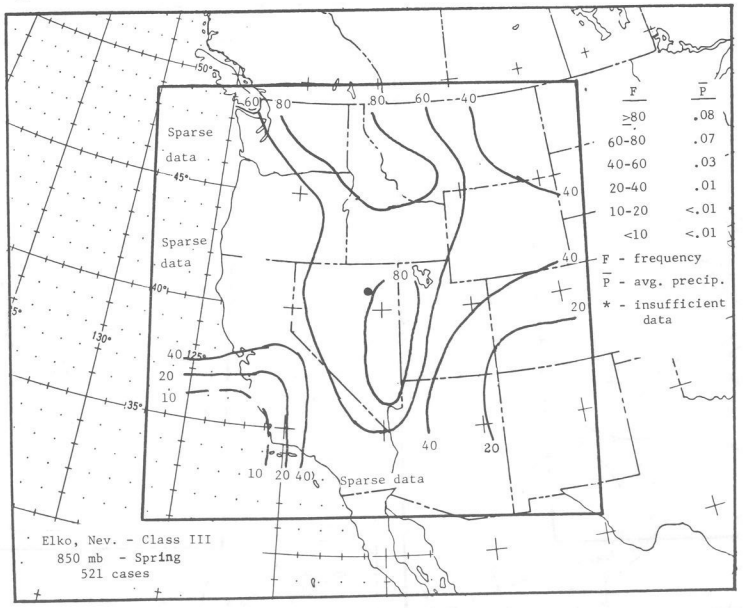



Chart 10 - IIIa

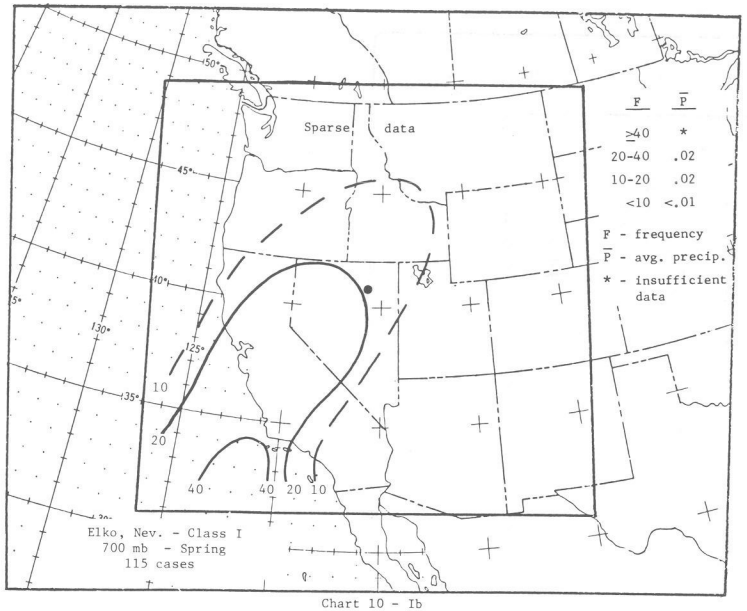



Chart 10 - Ib

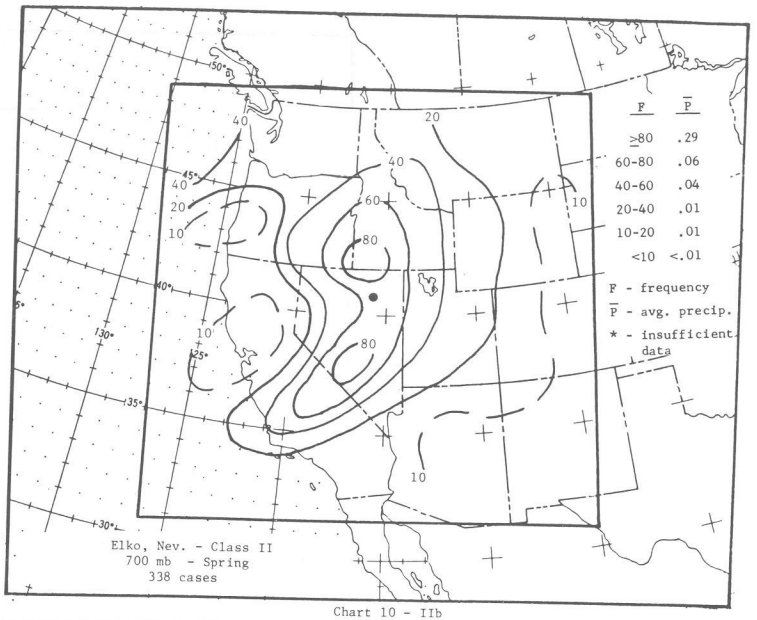



Chart 10 - IIb

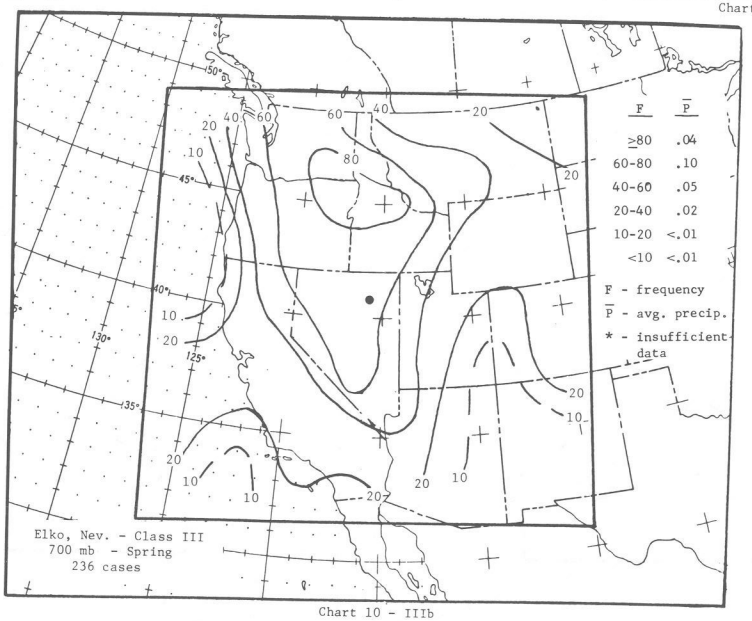



Chart 10 - IIIb

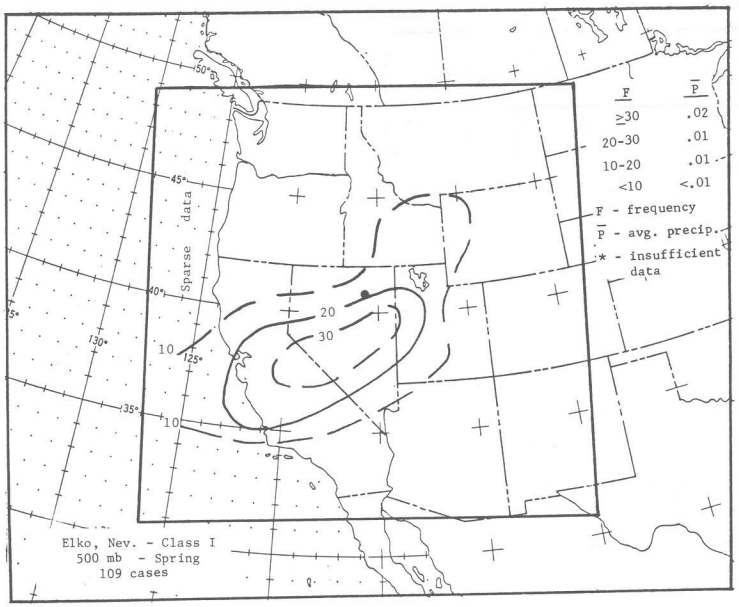



Chart 10 - Ic

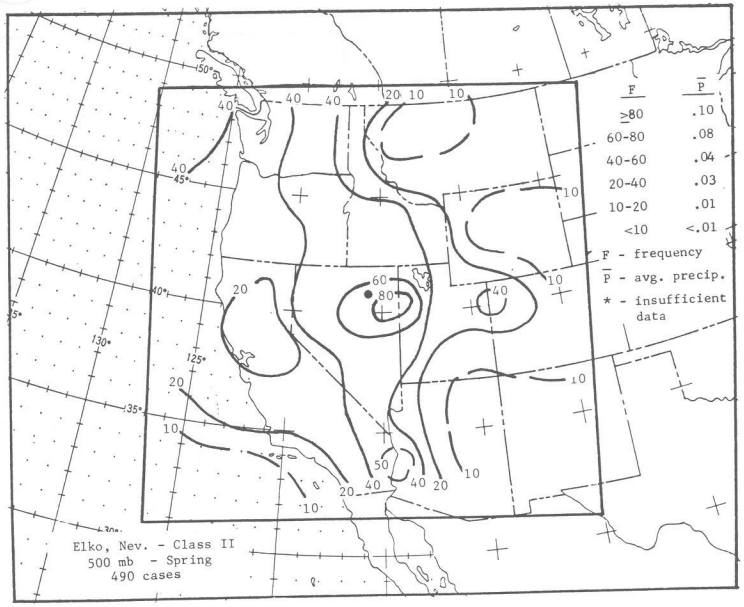



Chart 10 - IIc

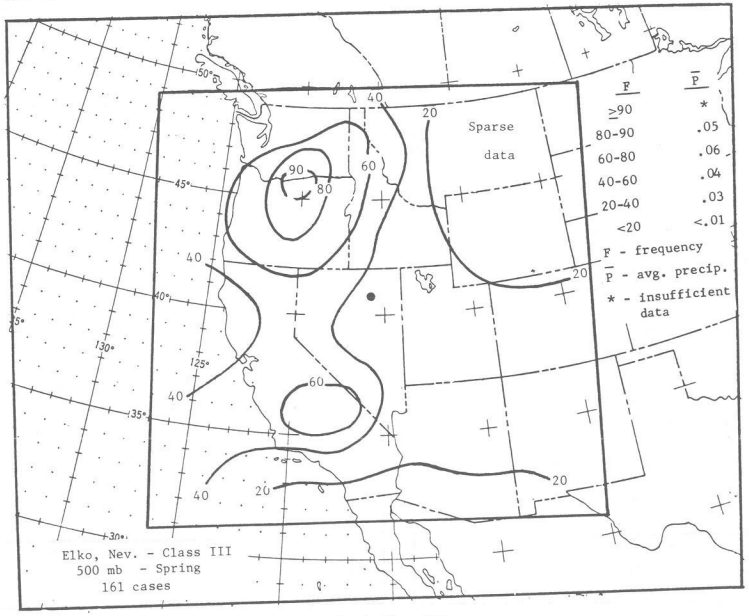



Chart 10 - IIIc

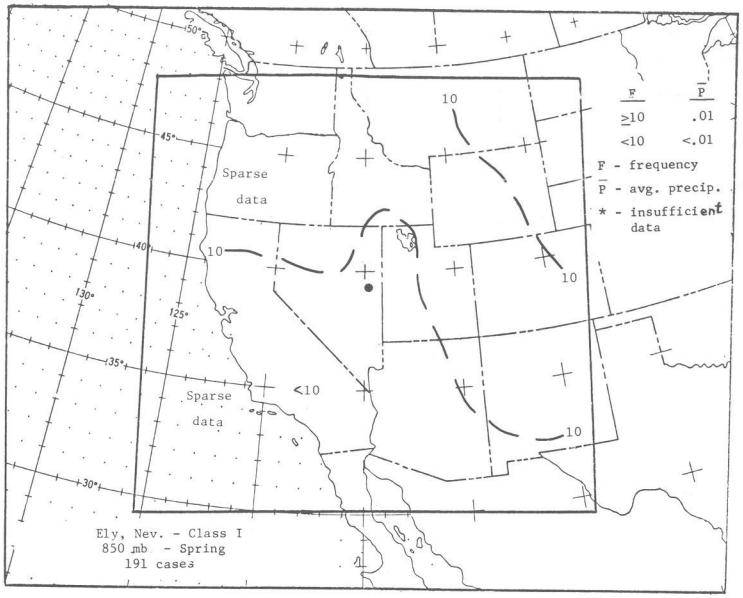



Chart 11 - Ia

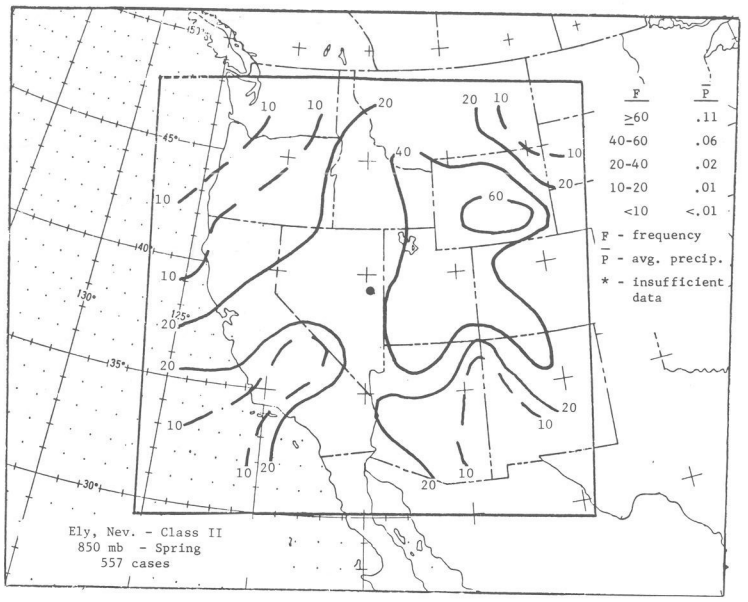



Chart 11 - IIa

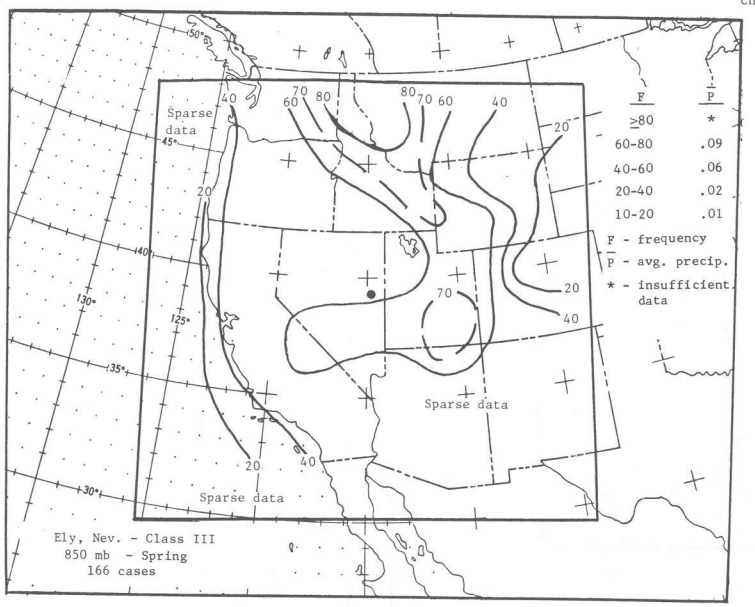



Chart 11 - IIIa

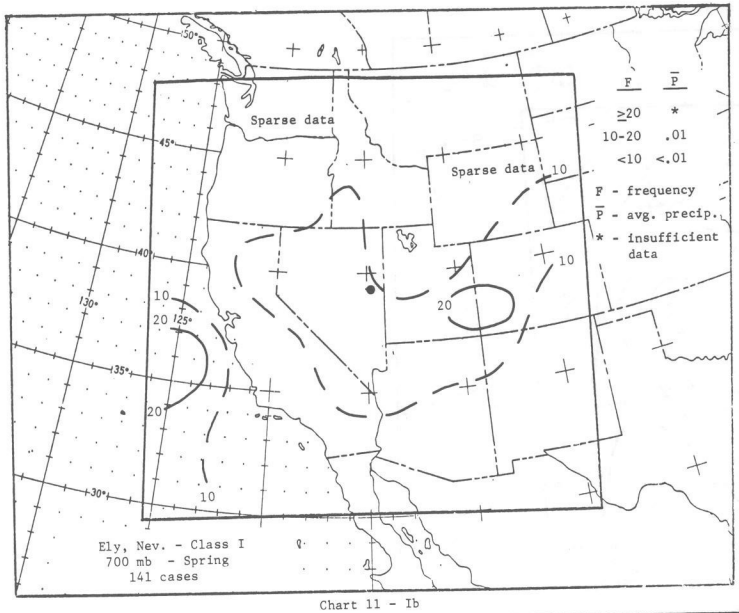



Chart 11 - Ib

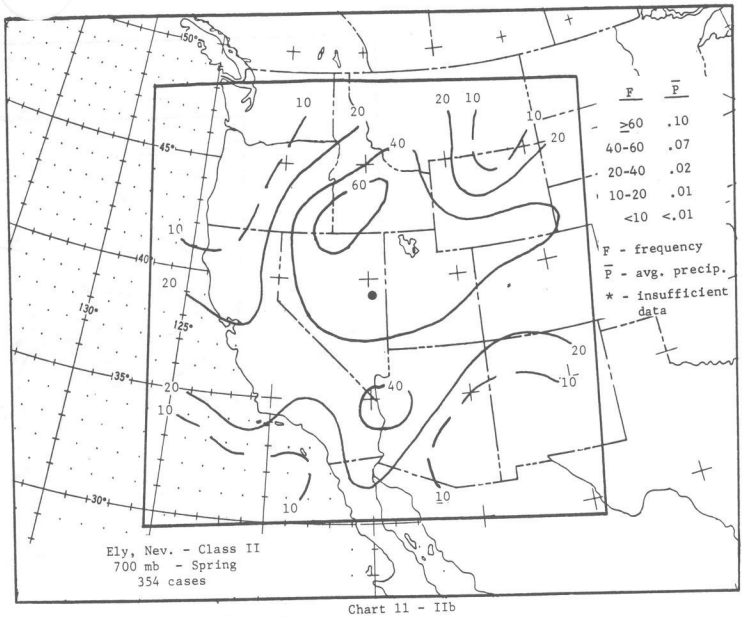



Chart 11 - IIb

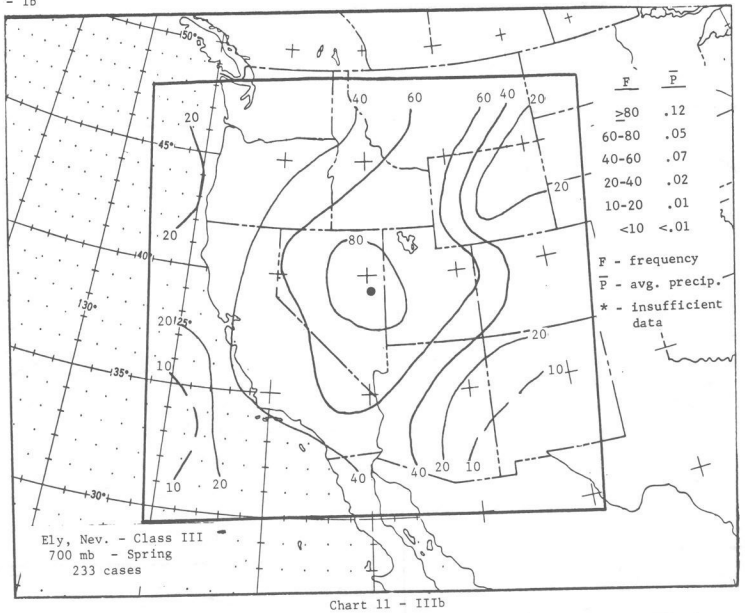



Chart 11 - IIIb

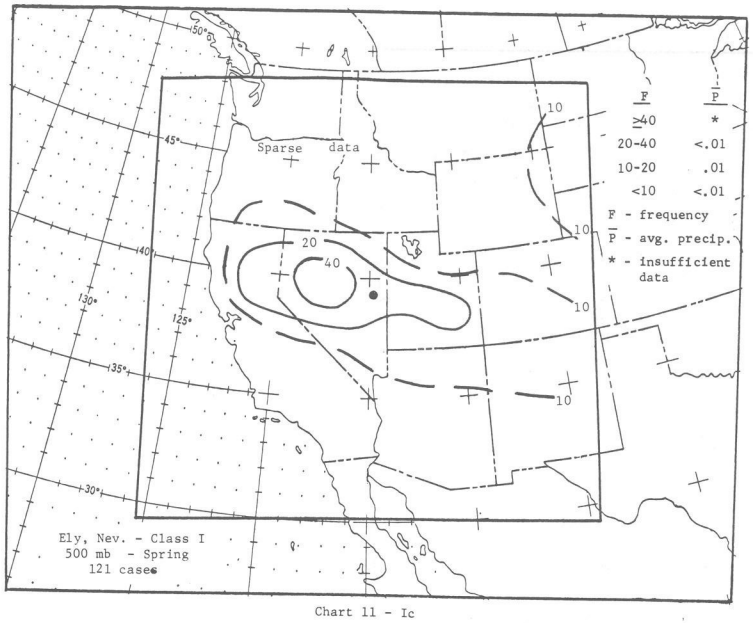



Chart 11 - Ic

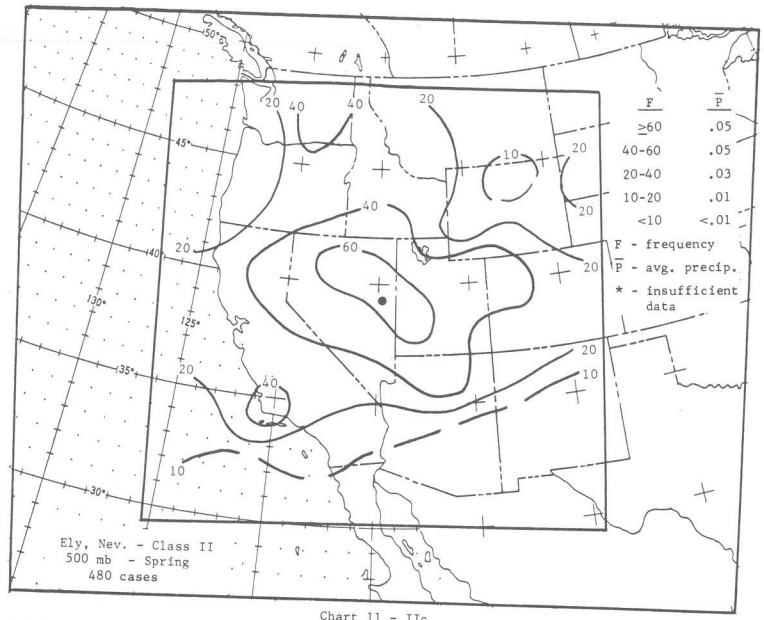



Chart 11 - IIc

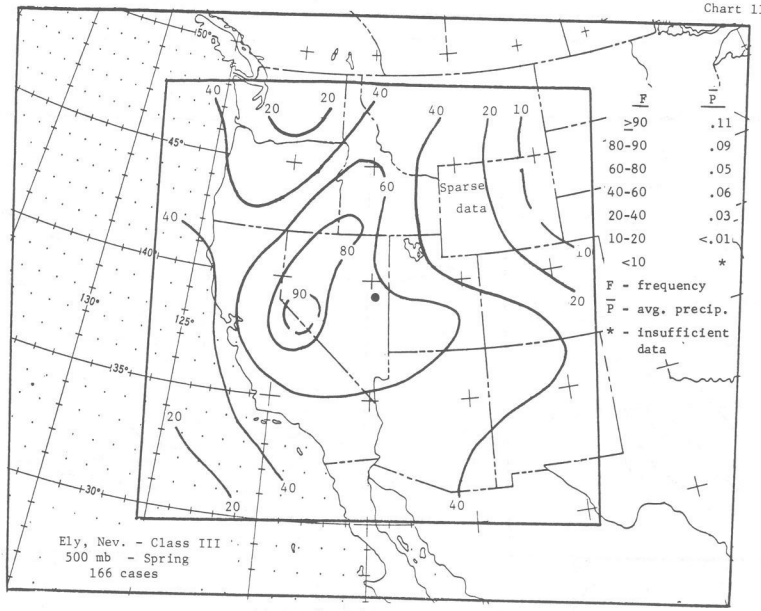



Chart 11 - IIIc

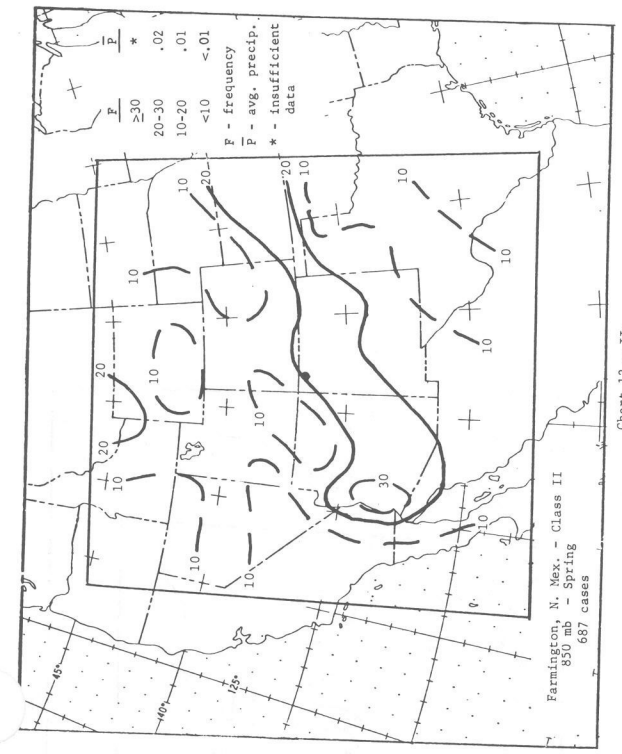



Chart 12 - IIa

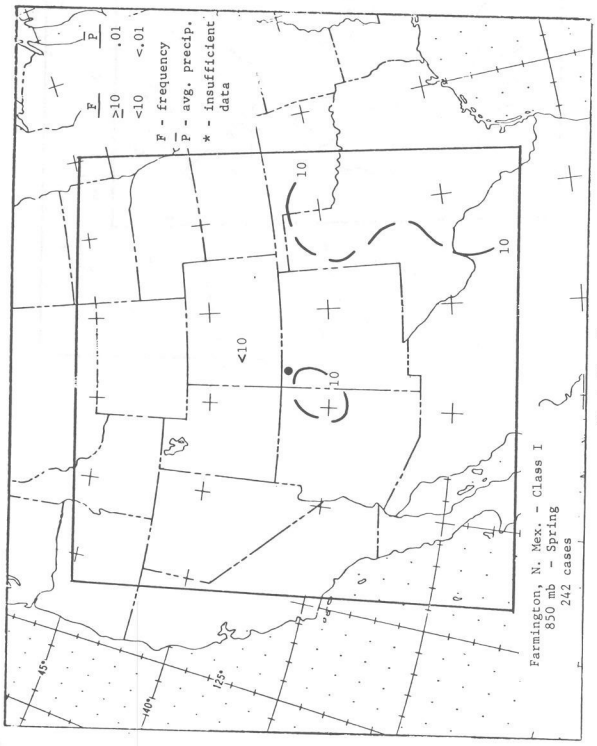



Chart 12 - Ia

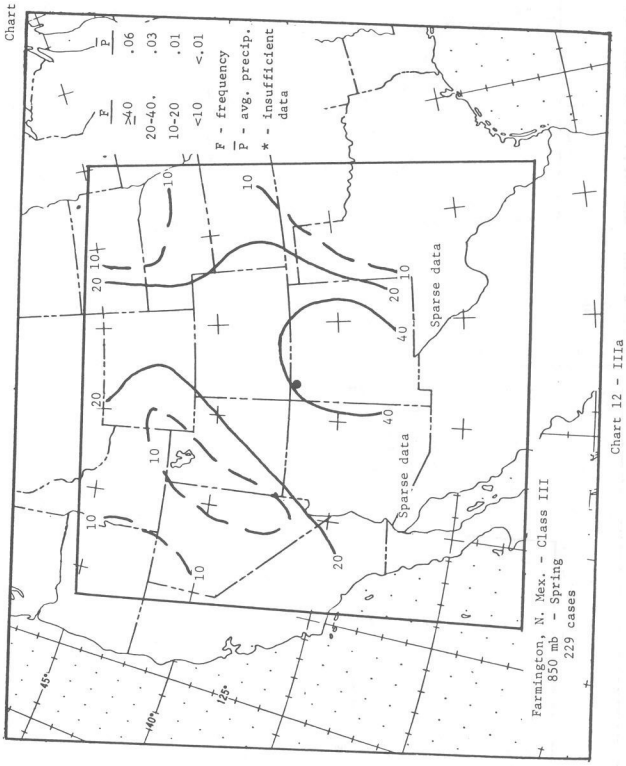



Chart 12 - IIIa

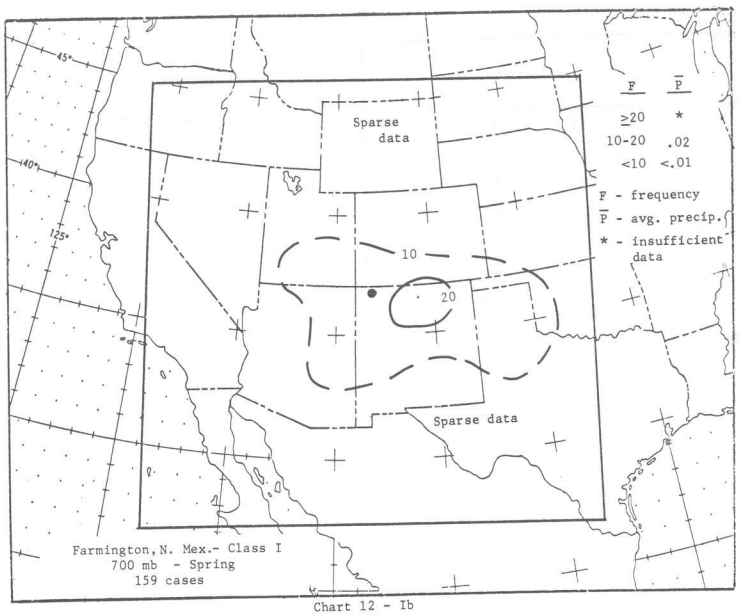



Chart 12 - Ib

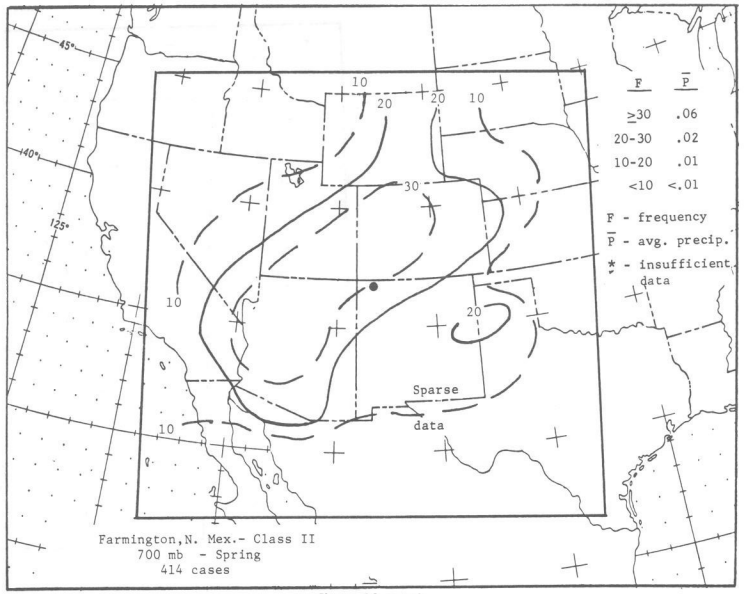



Chart 12 - IIb

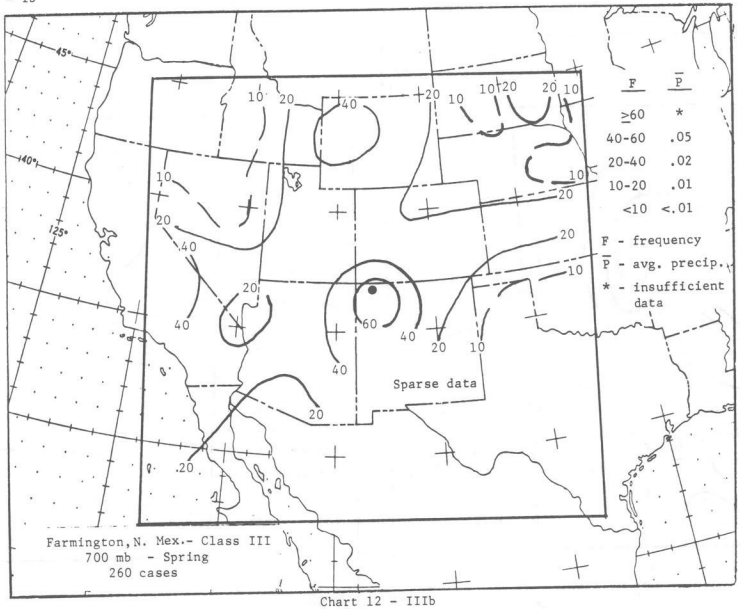



Chart 12 - IIIb

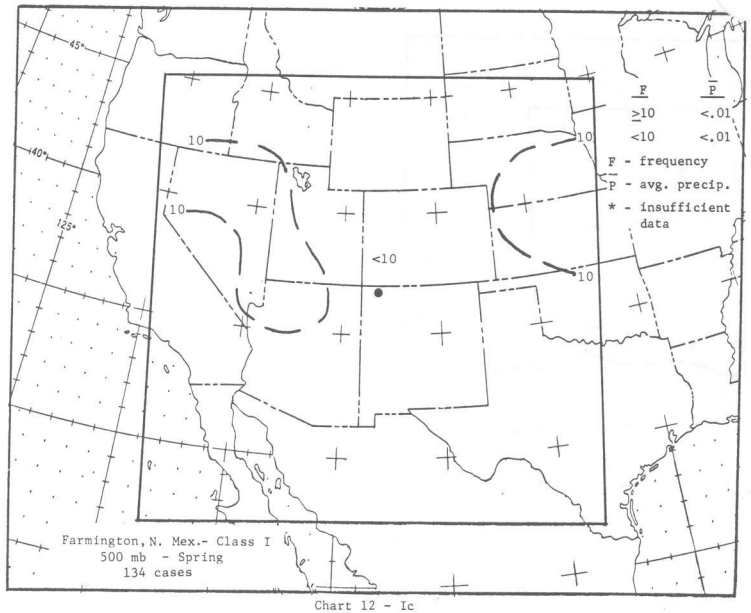



Chart 12 - Ic

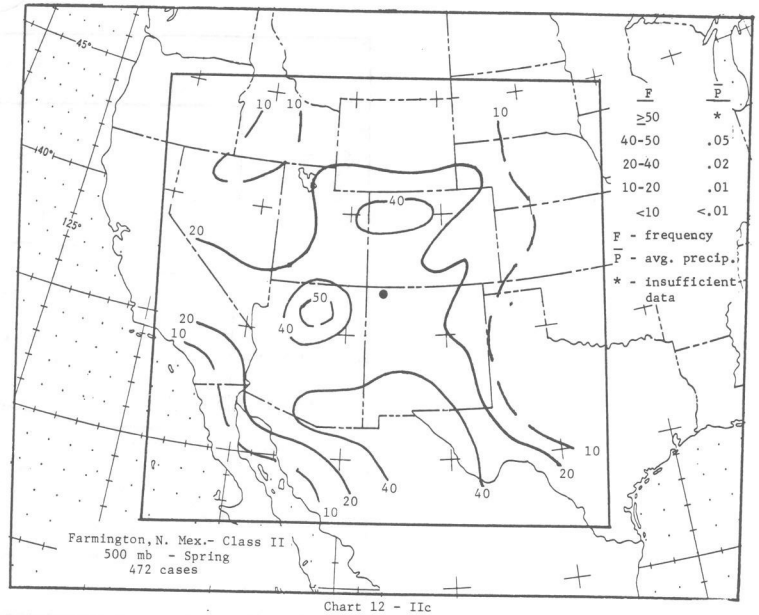



Chart 12 - IIc

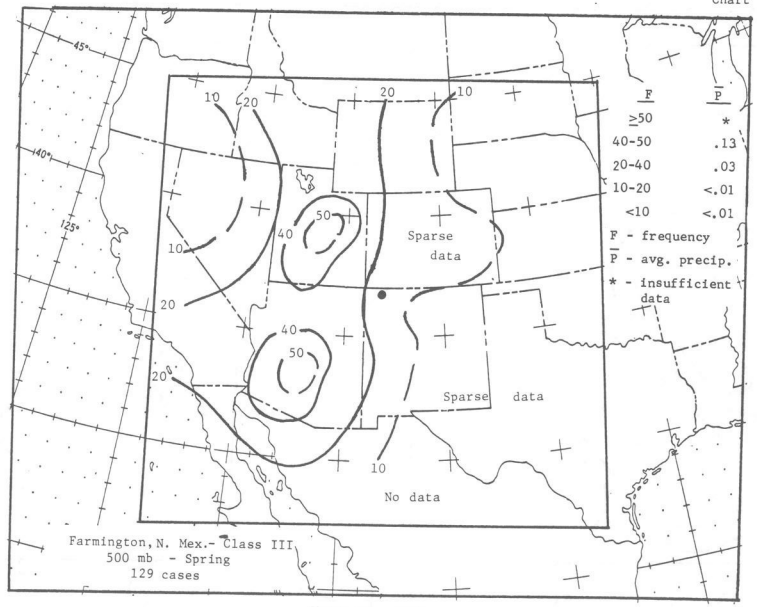



Chart 12 - IIIc

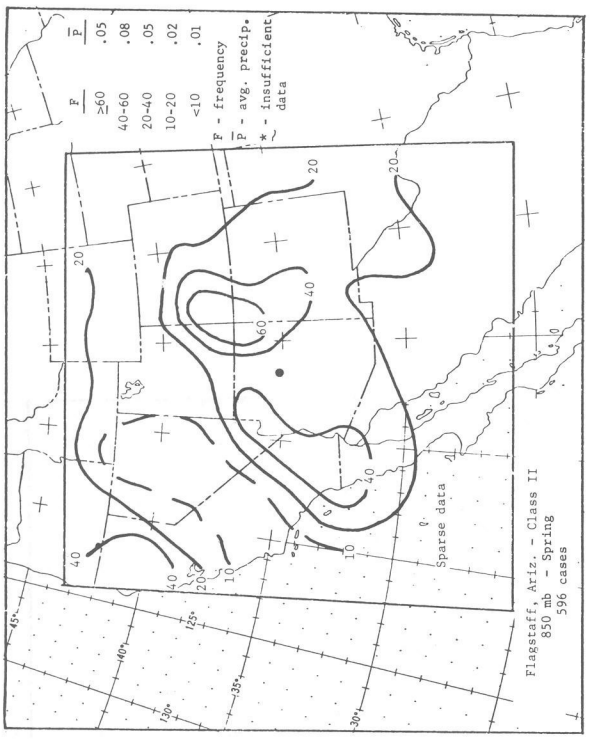



Chart 13 - IIa

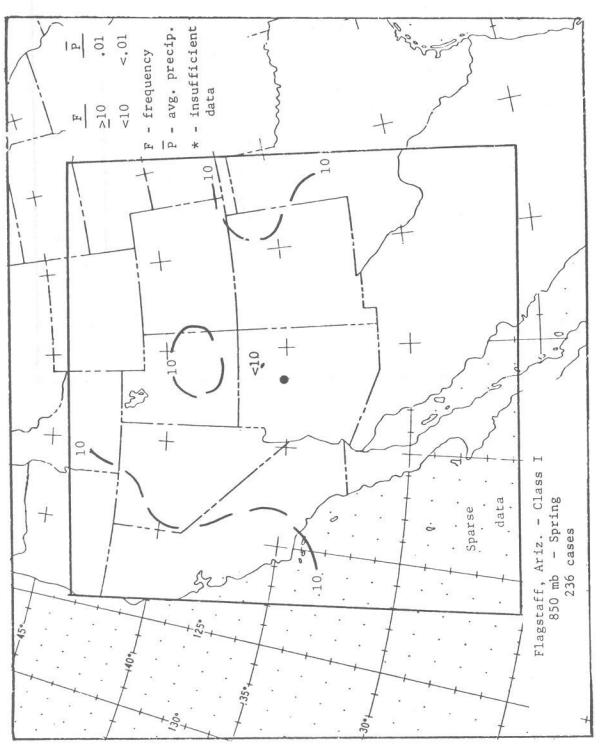
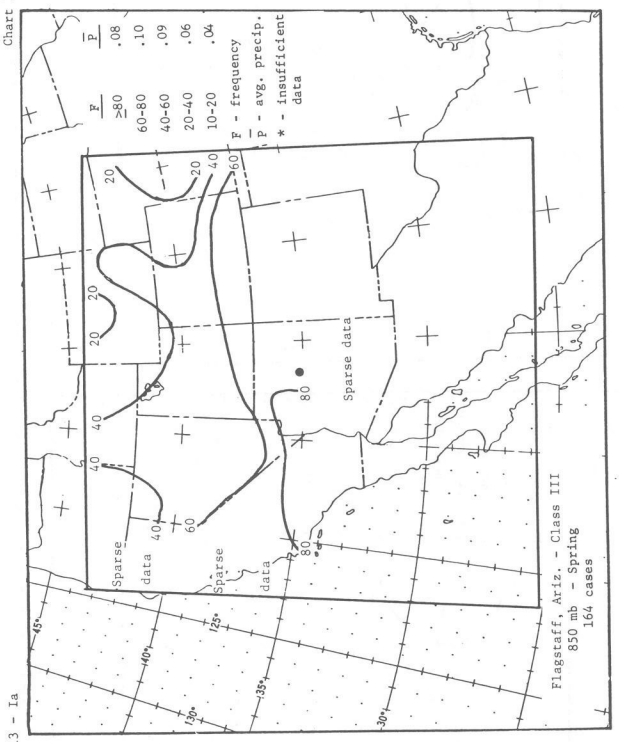



Chart 13 - Ia




Ch - IIIa

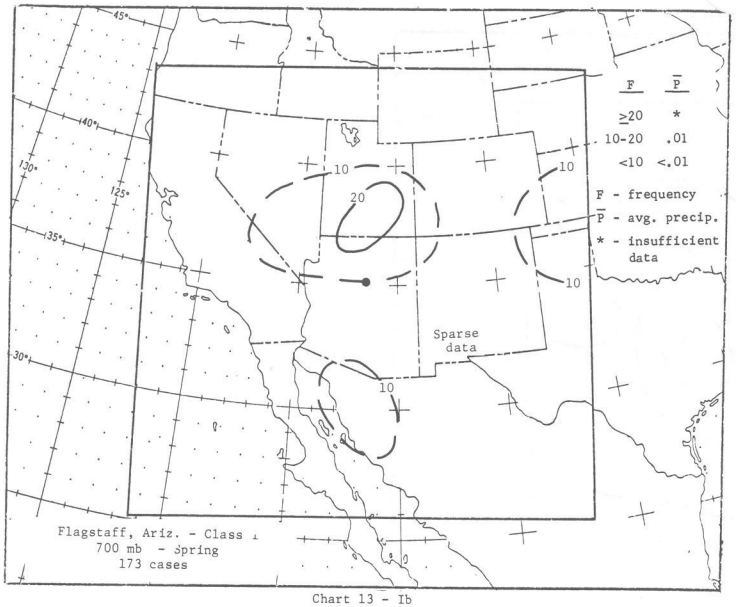



Chart 13 - Ib

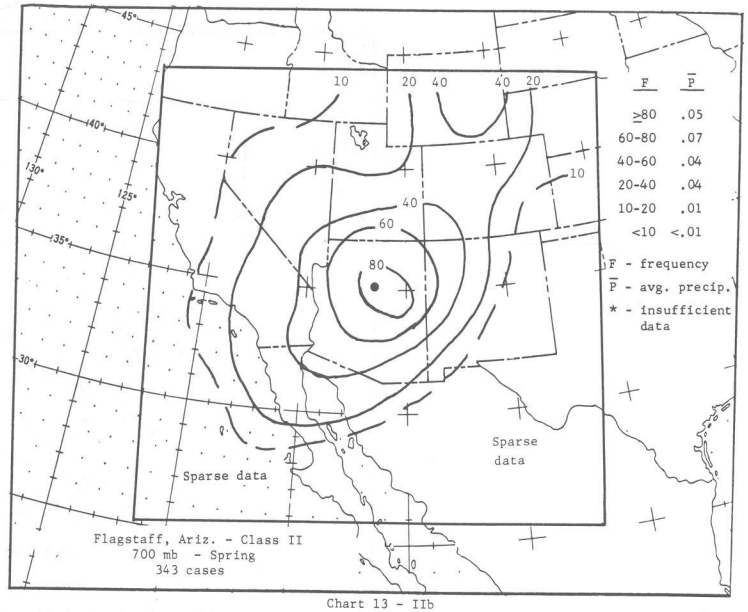



Chart 13 - IIb

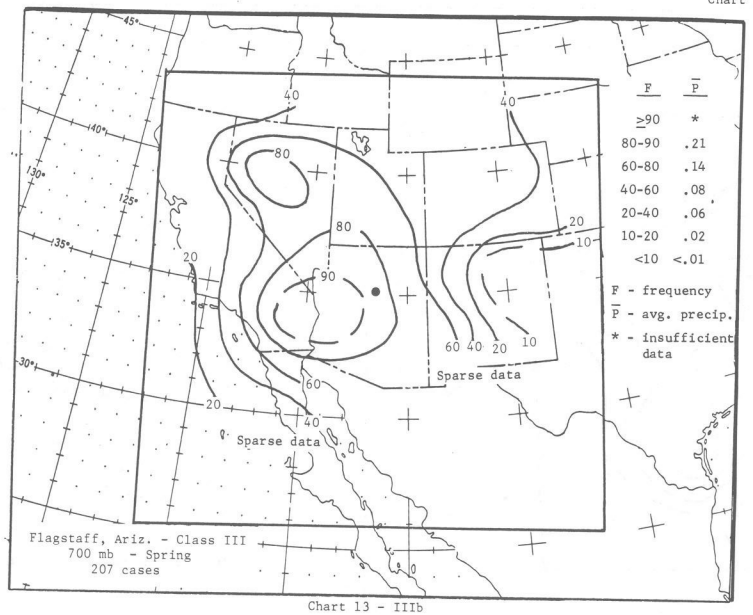



Chart 13 - IIIb

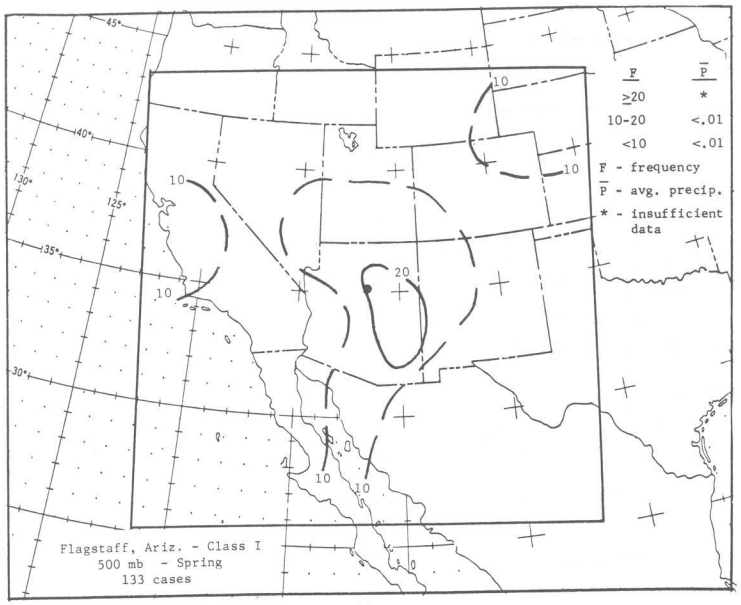



Chart 13 - Ic

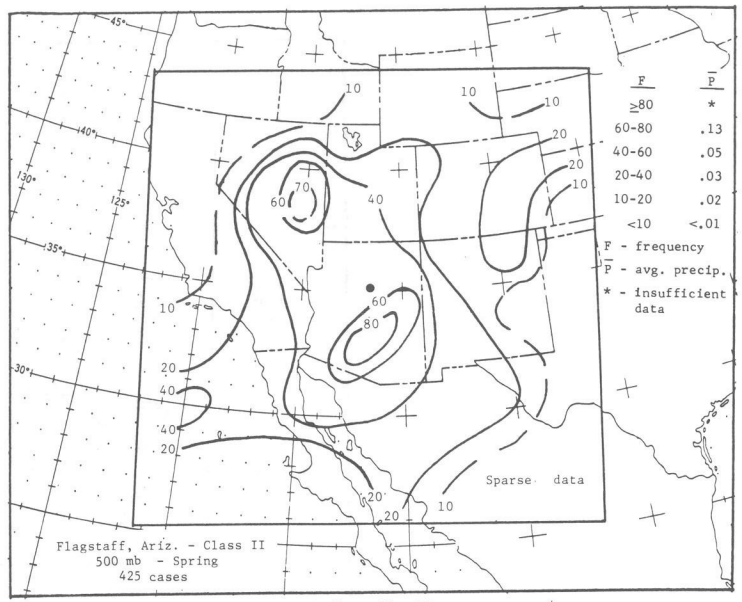



Chart 13 - IIc

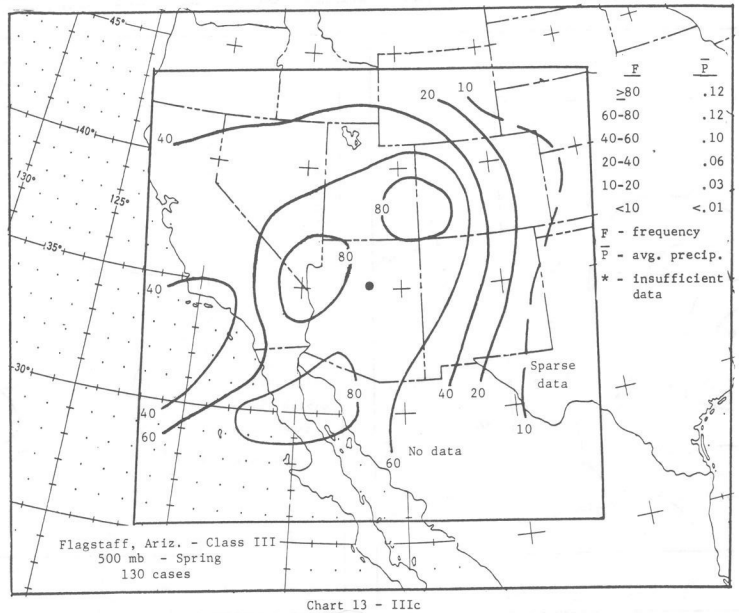



Chart 13 - IIIc

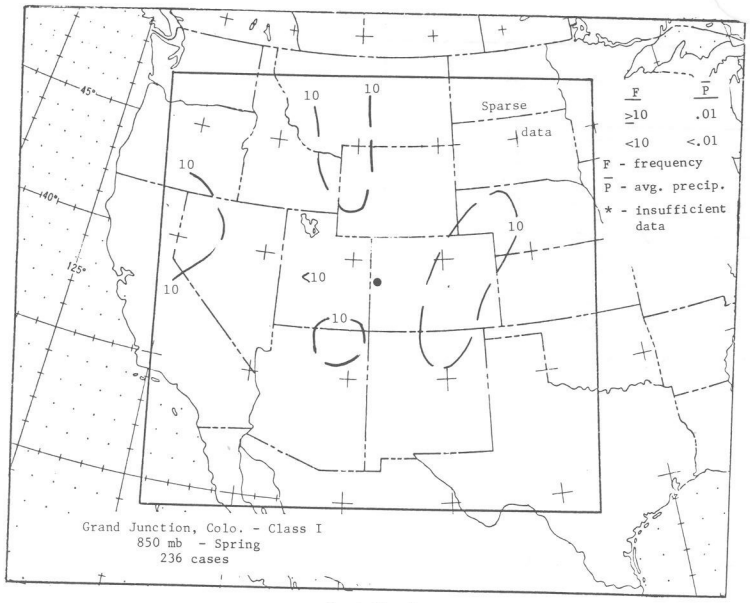



Chart 14 - Ia

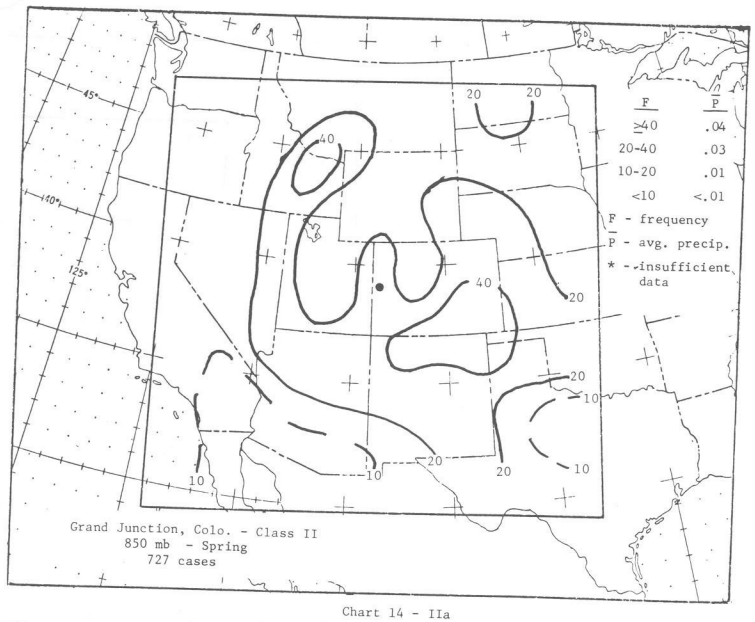



Chart 14 - IIa

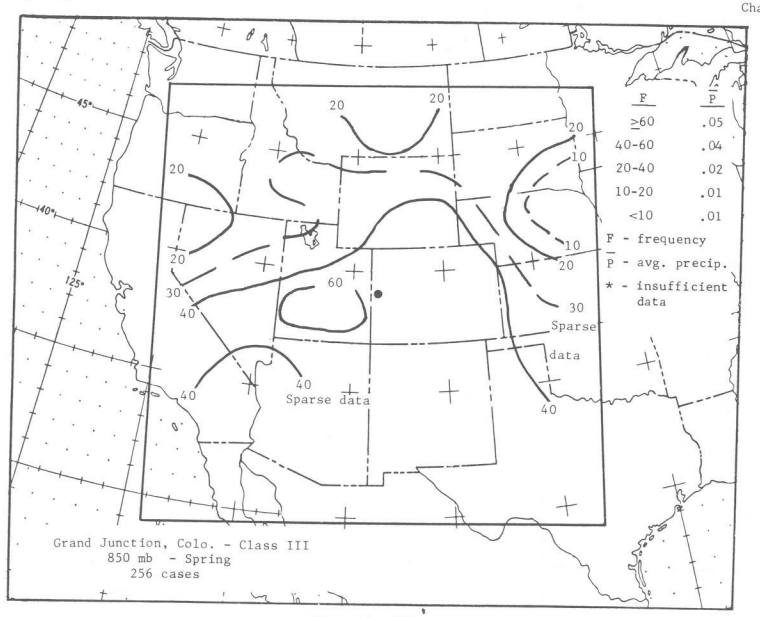



Chart 14 - IIIa

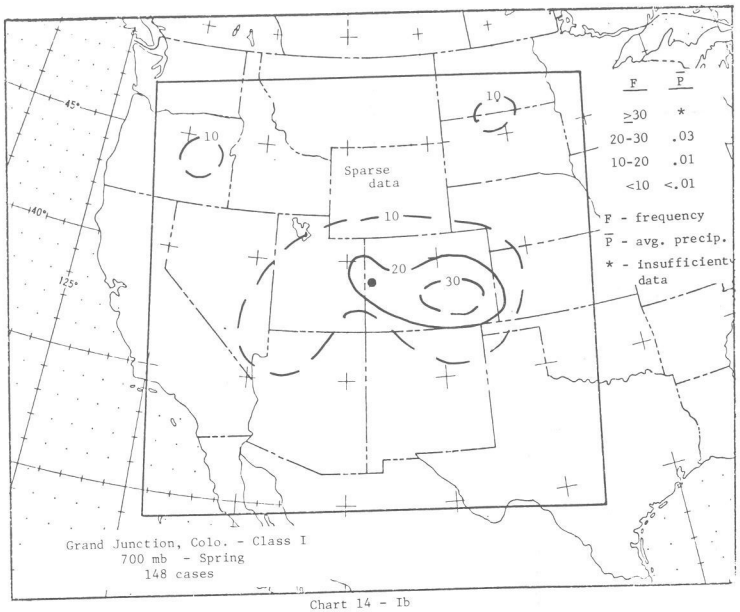



Chart 14 - Ib

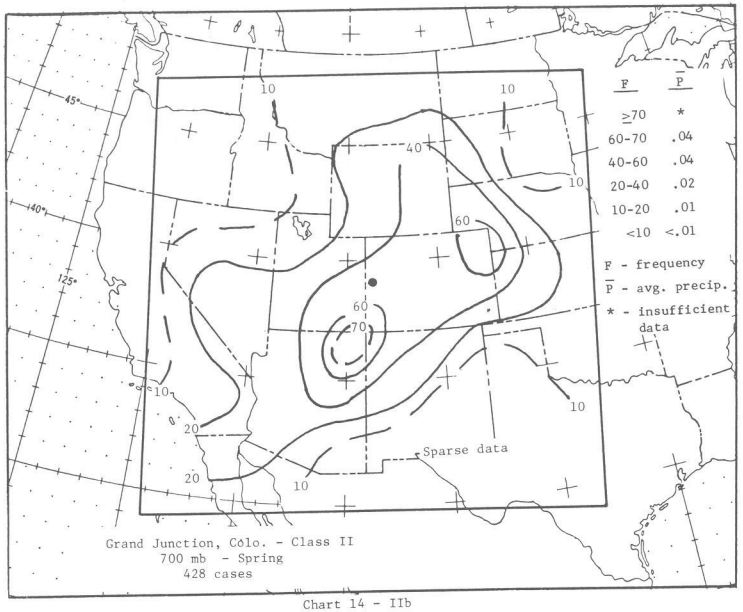



Chart 14 - IIb

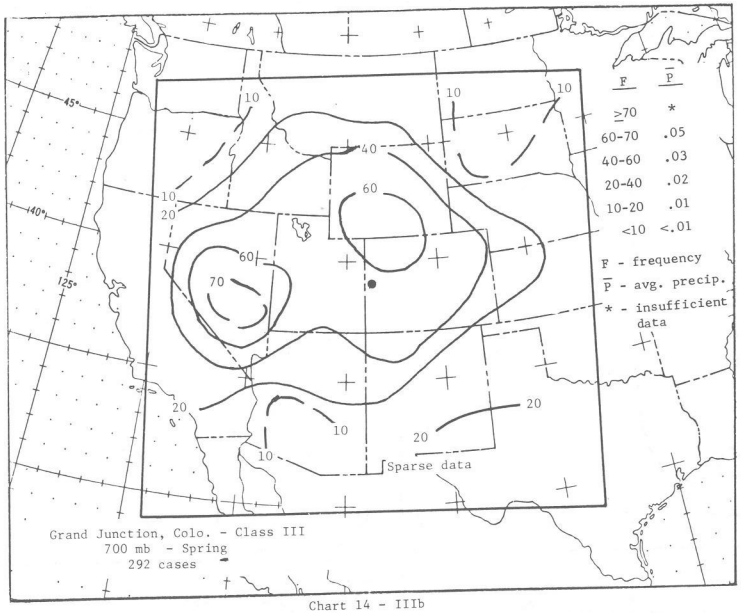



Chart 14 - IIIb

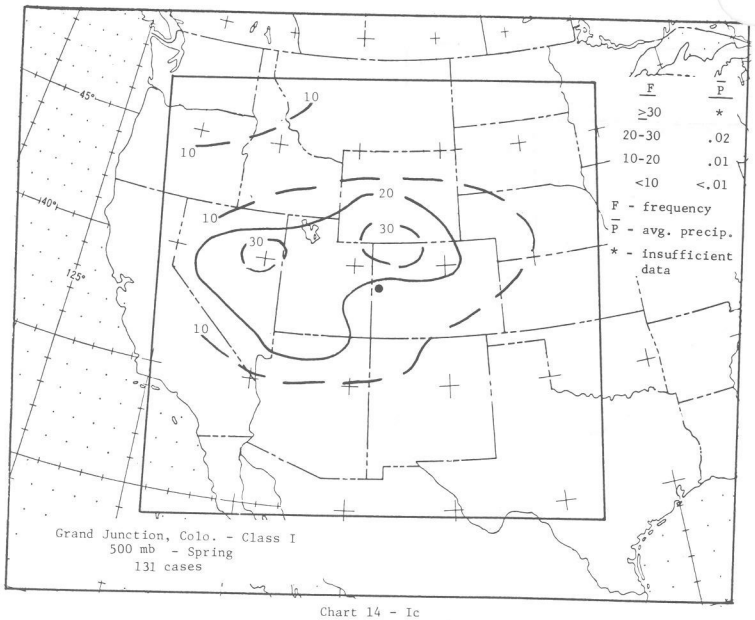



Chart 14 - Ic

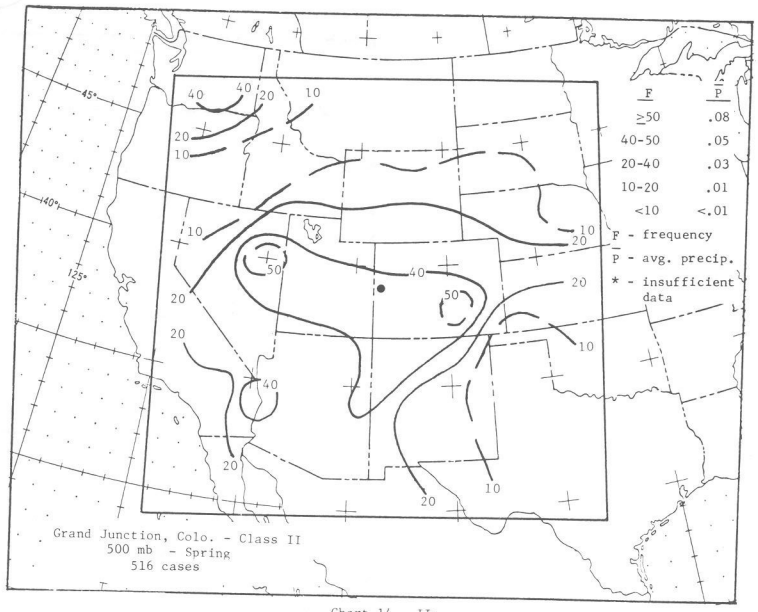



Chart 14 - IIc

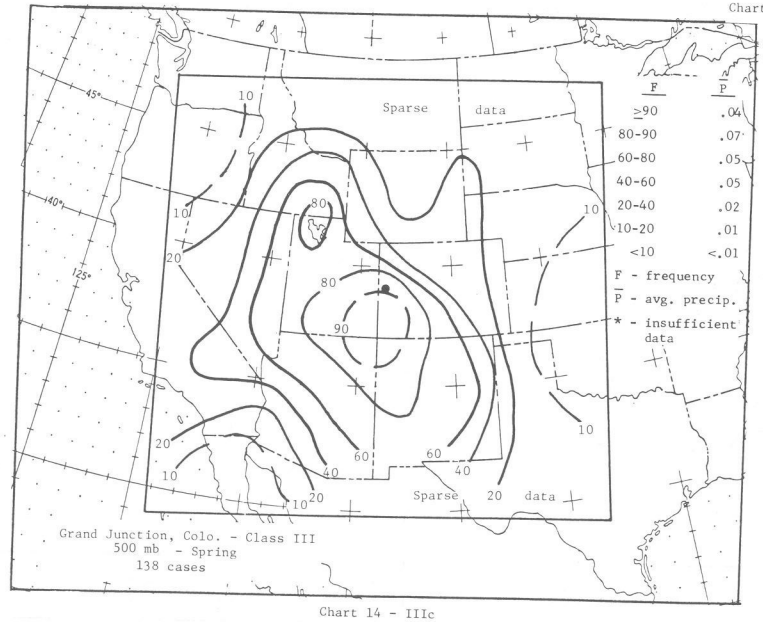



Chart 14 - IIIc

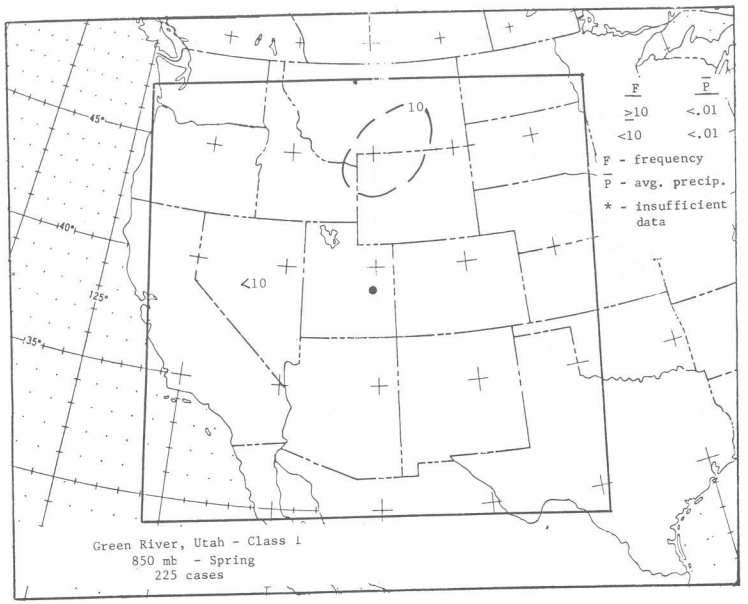



Chart 15 - Ia

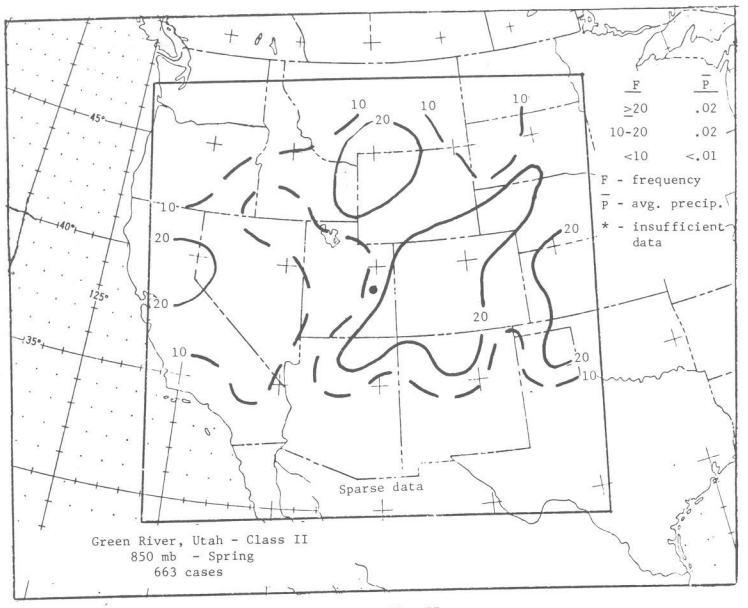



Chart 15 - IIa

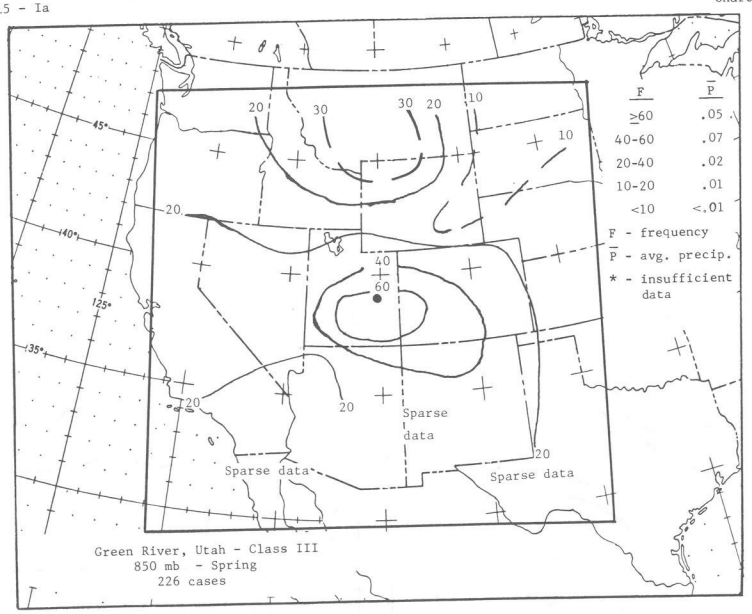



Chart 15 - IIIa

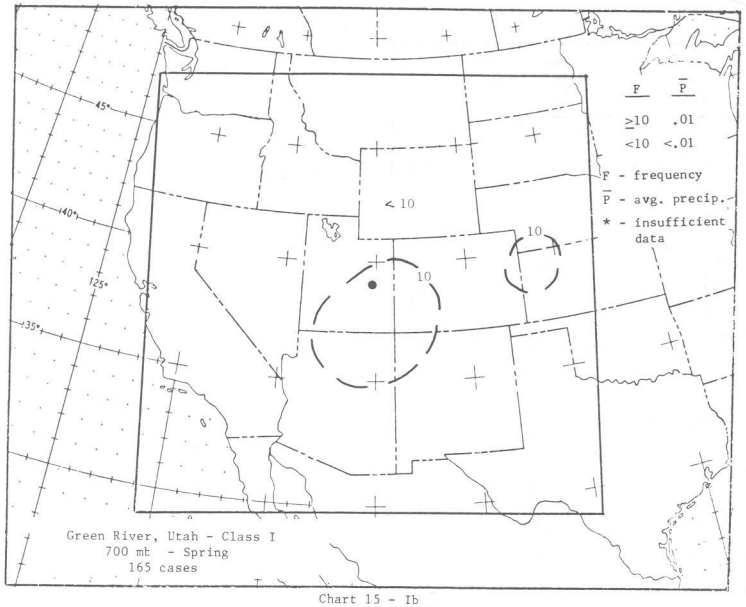



Chart 15 - Ib

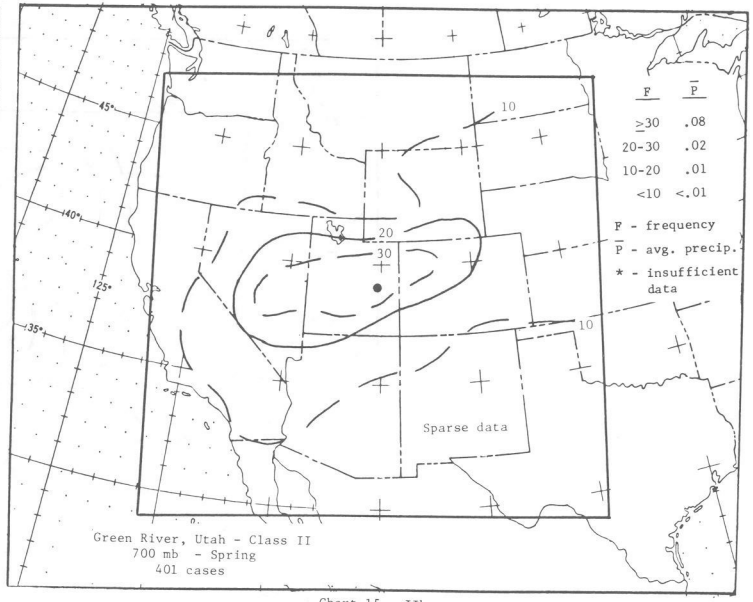



Chart 15 - IIb

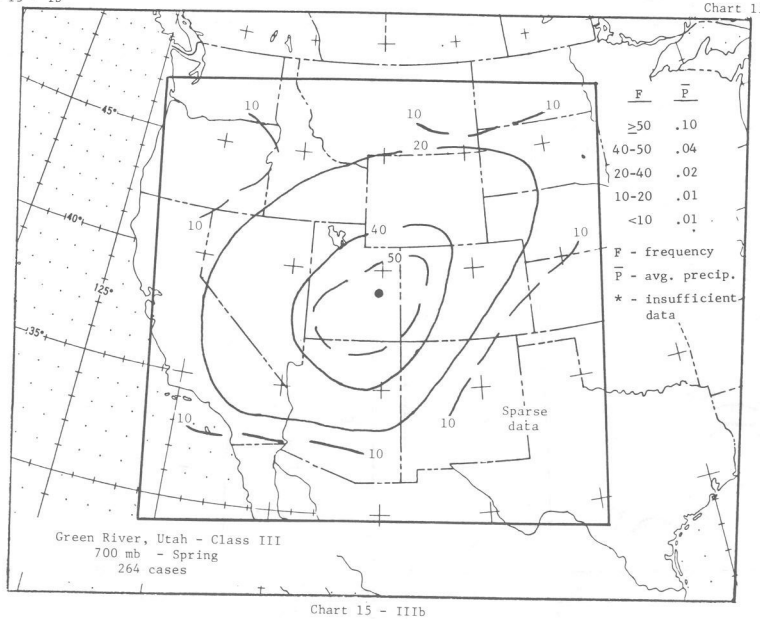



Chart 15 - IIIb

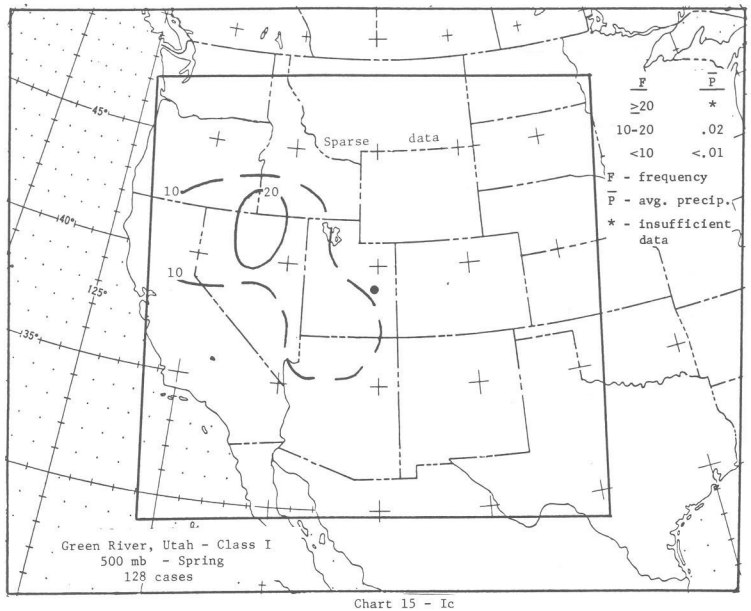



Chart 15 - Ic

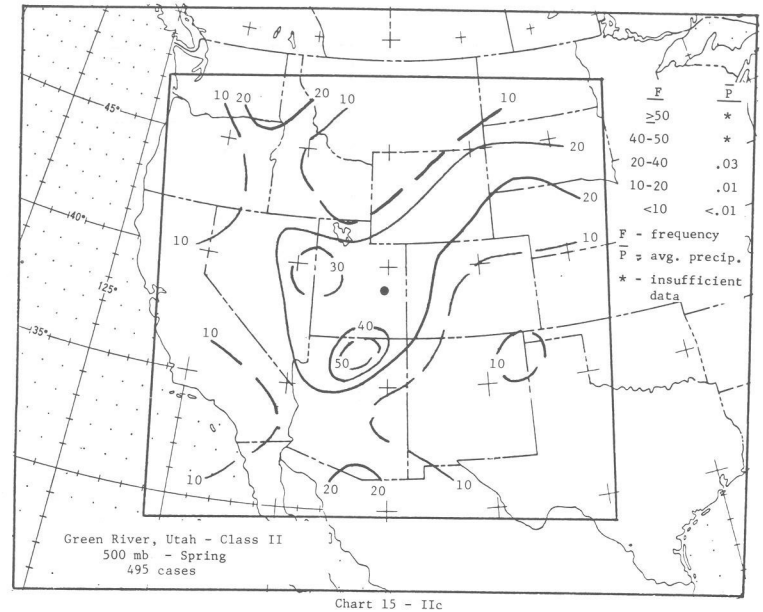



Chart 15 - IIc

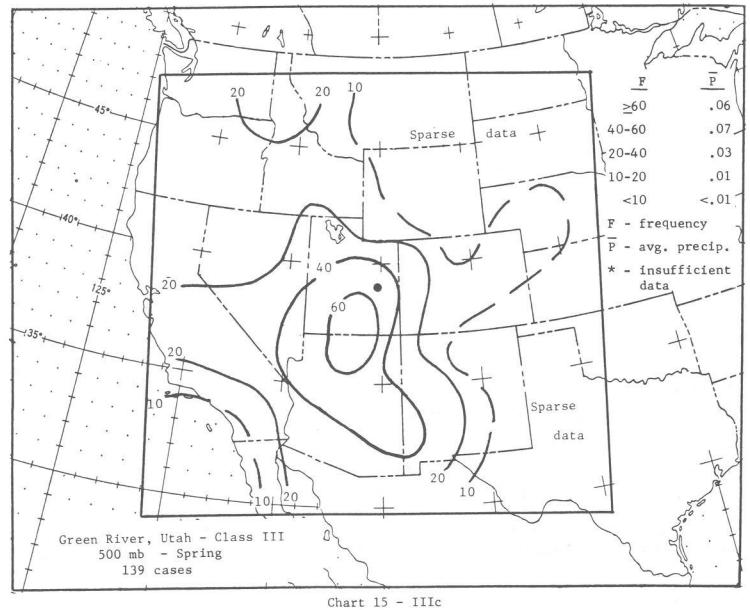



Chart 15 - IIIc

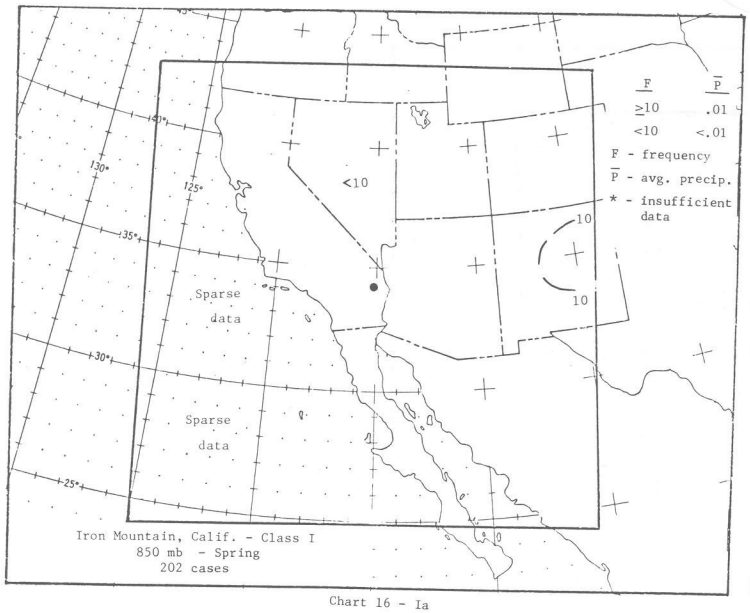



Chart 16 - Ia

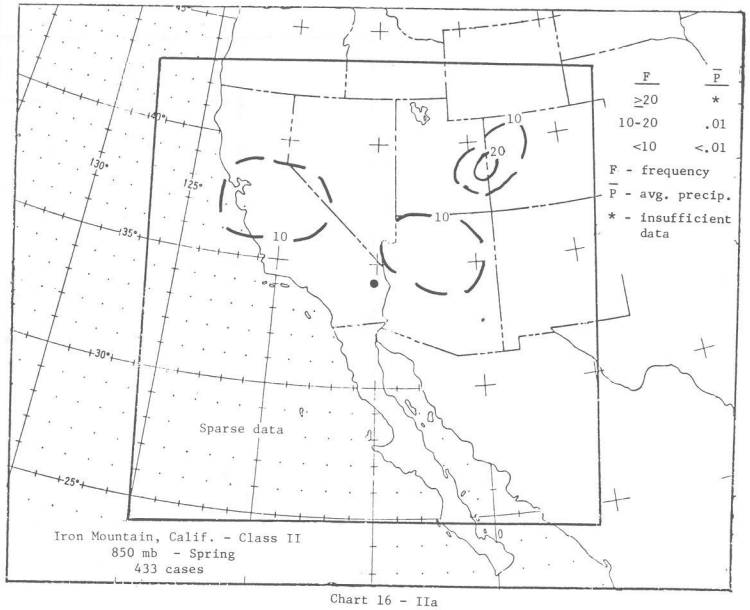



Chart 16 - IIa

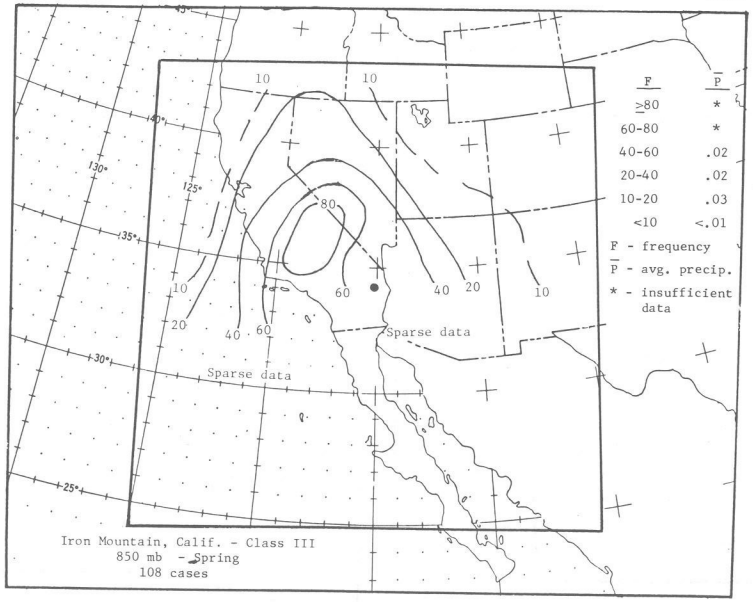



Chart 16 - IIIa

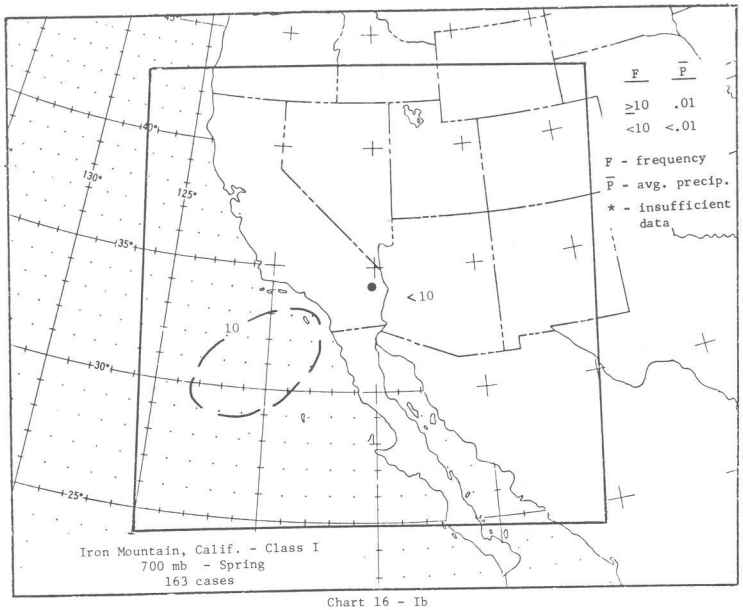



Chart 16 - Ib

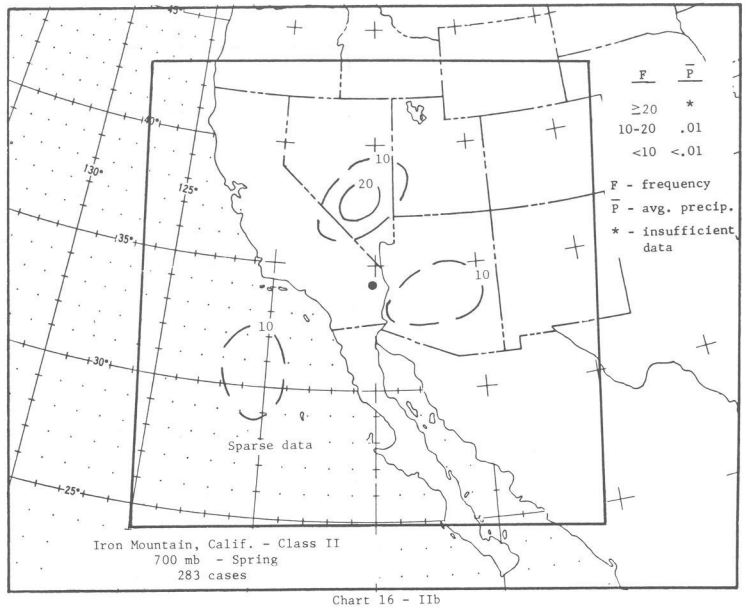



Chart 16 - IIb

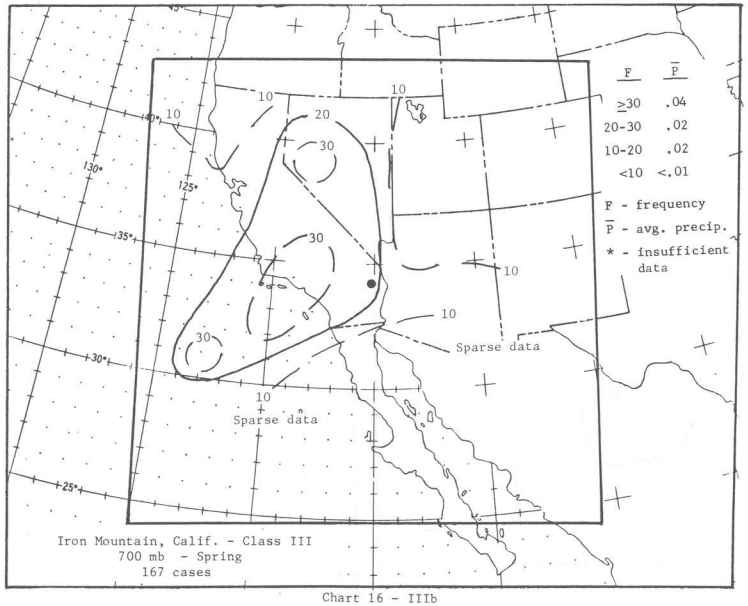



Chart 16 - IIIb

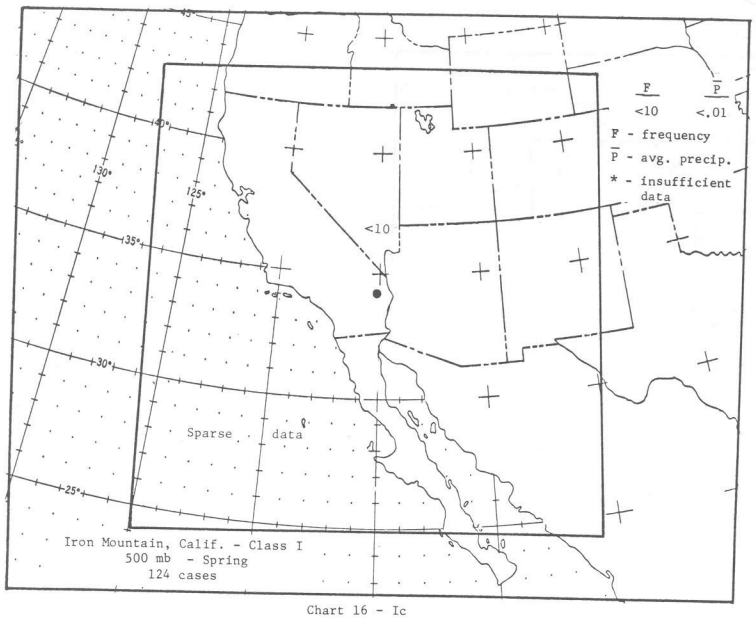



Chart 16 - Ic

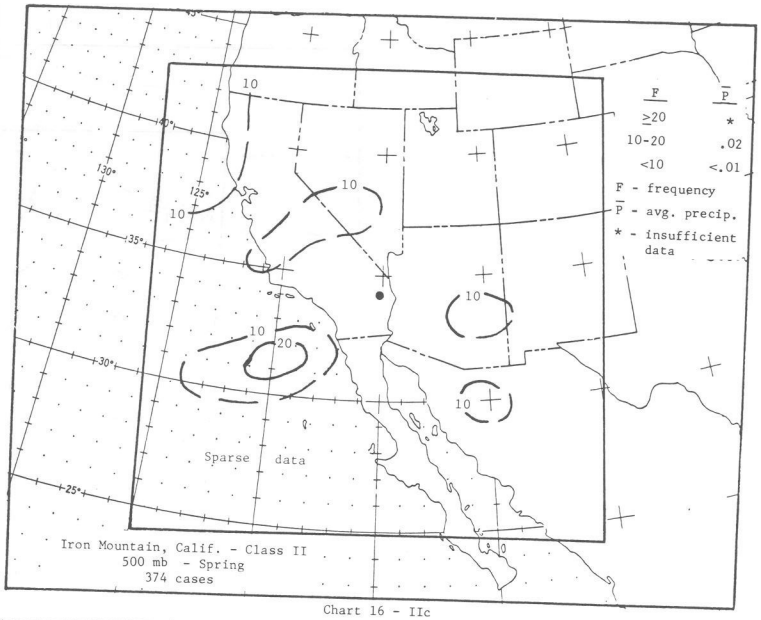



Chart 16 - IIc

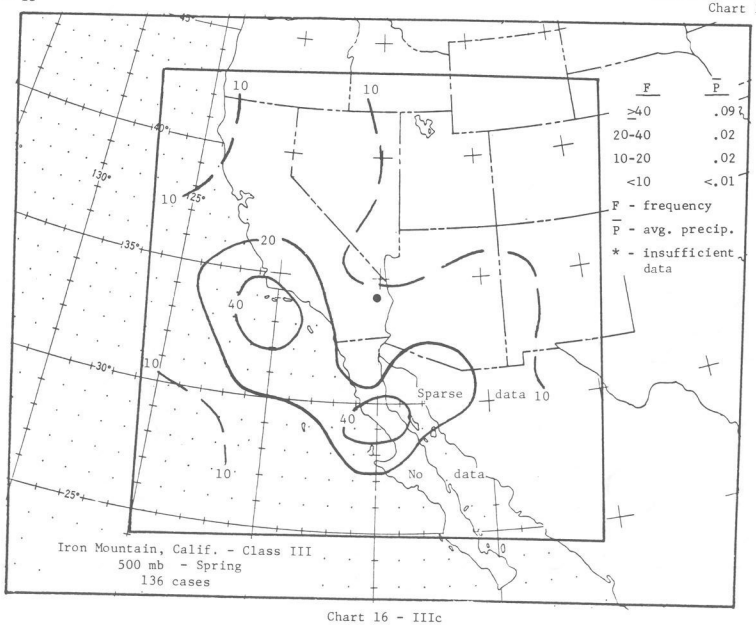



Chart 16 - IIIc

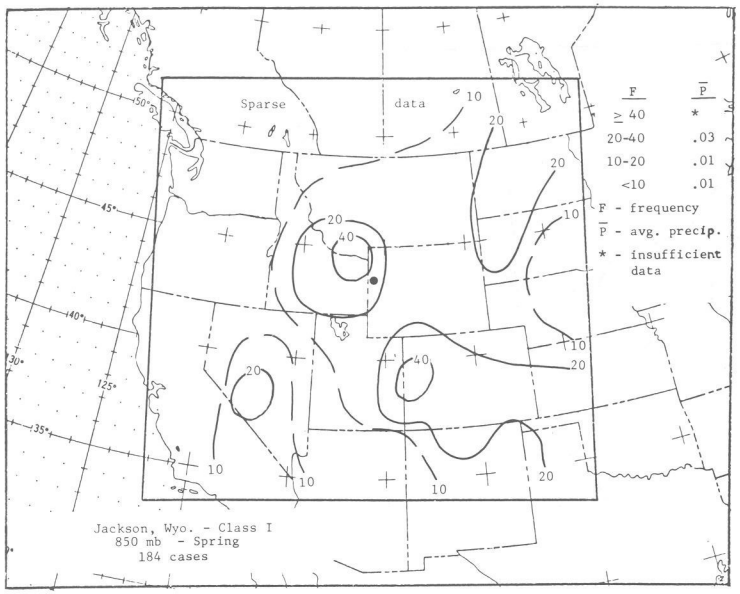



Chart 17 - Ia

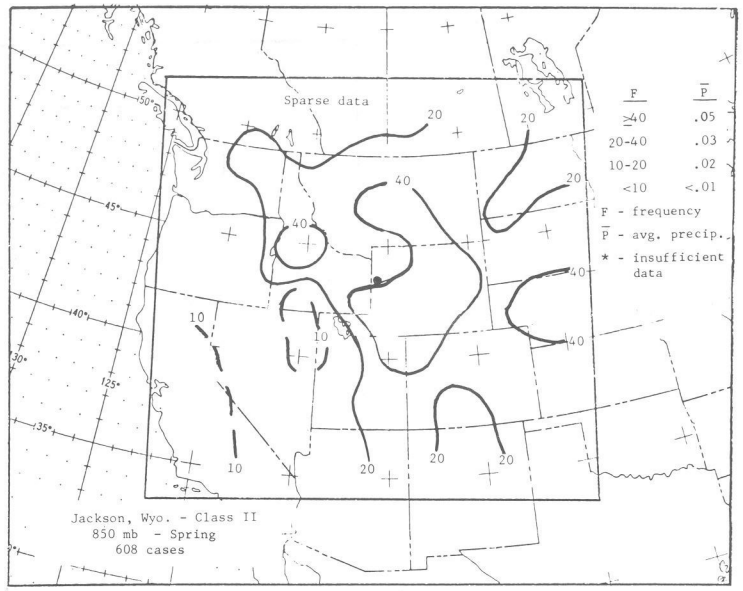



Chart 17 - IIa

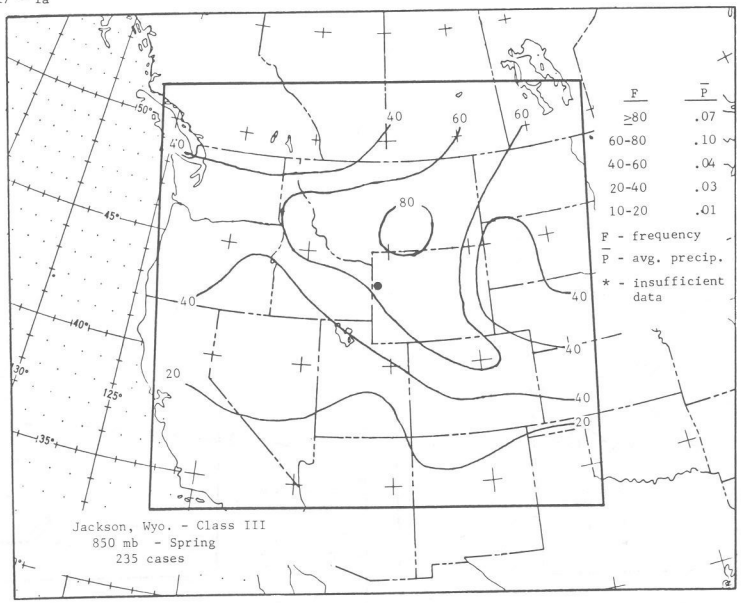



Chart 17 - IIIa

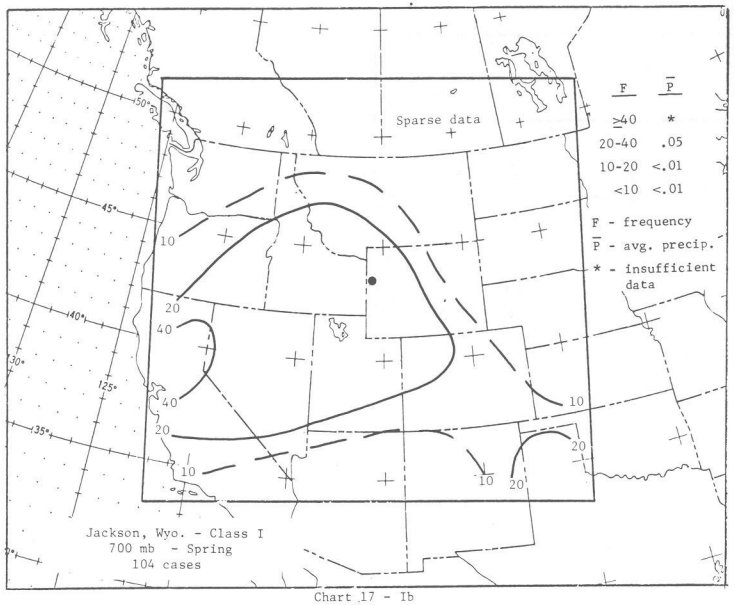



Chart 17 - Ib

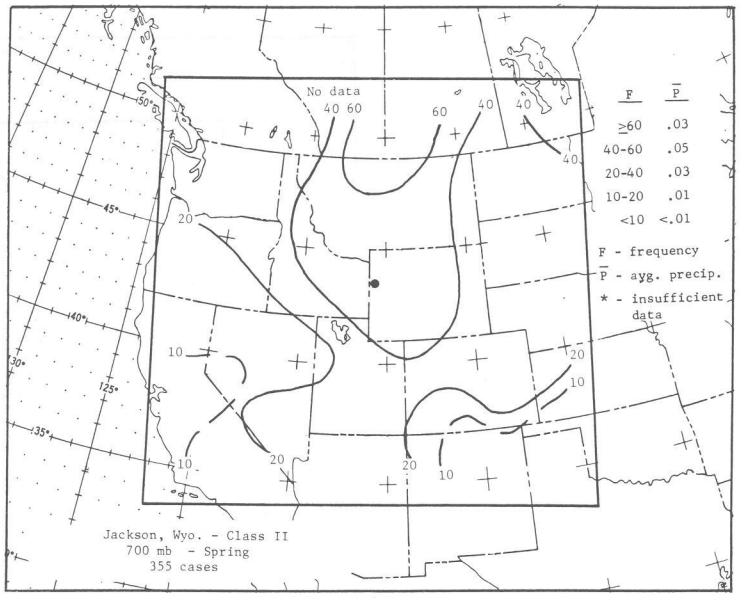



Chart 17 - IIb

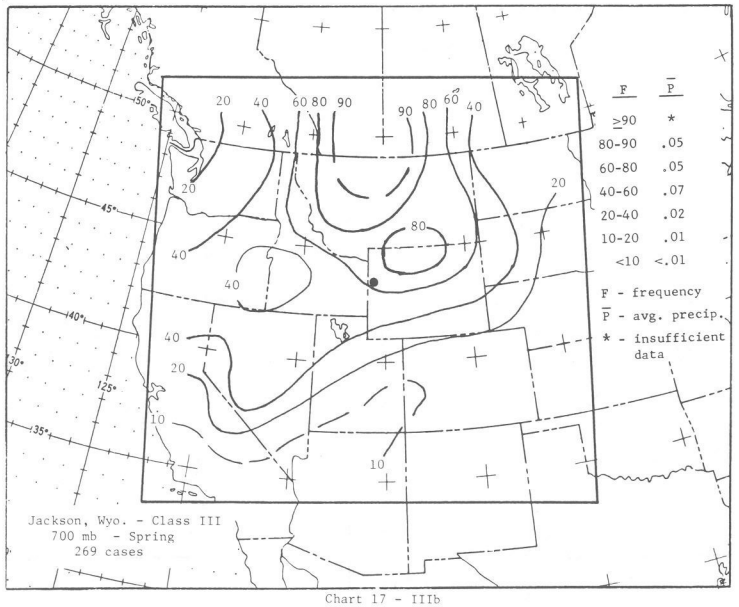



Chart 17 - IIIb

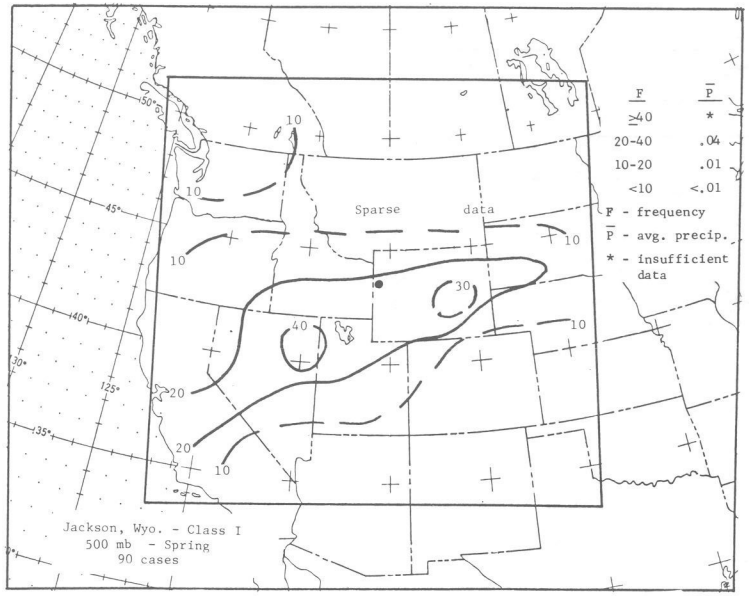



Chart 17 - Ic

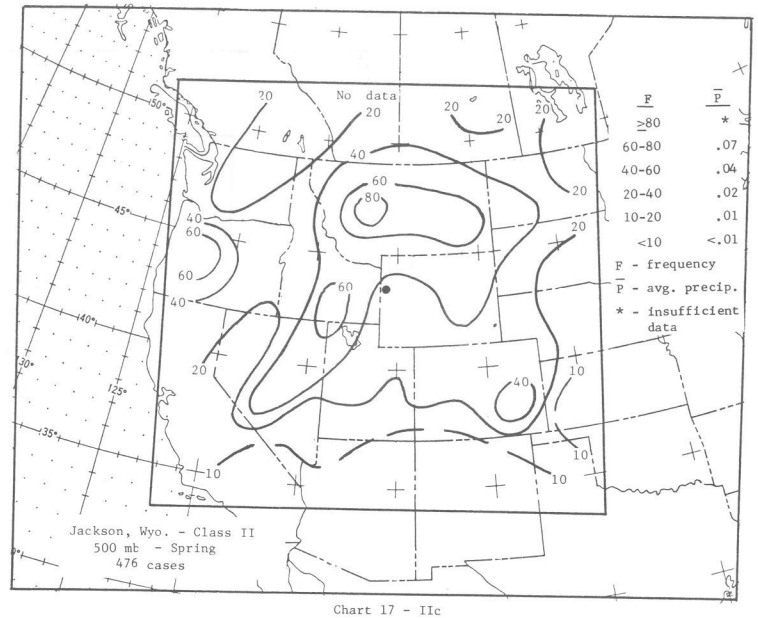



Chart 17 - IIc

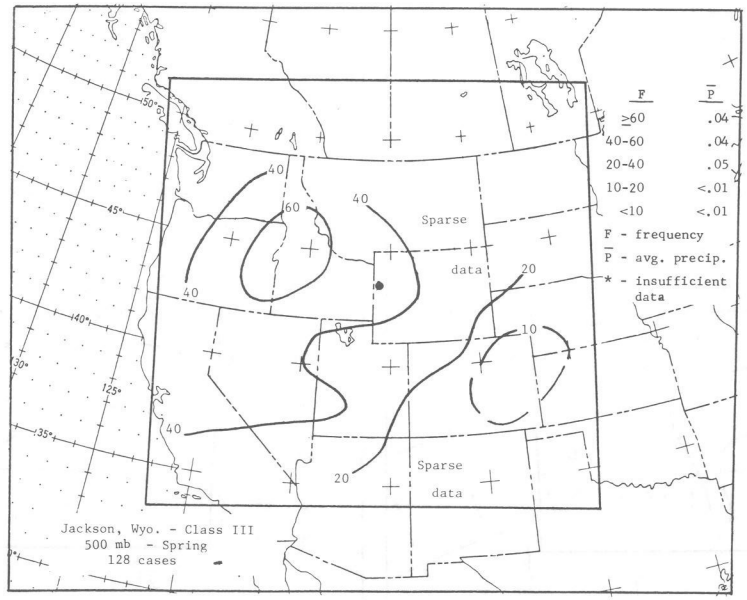



Chart 17 - IIIc

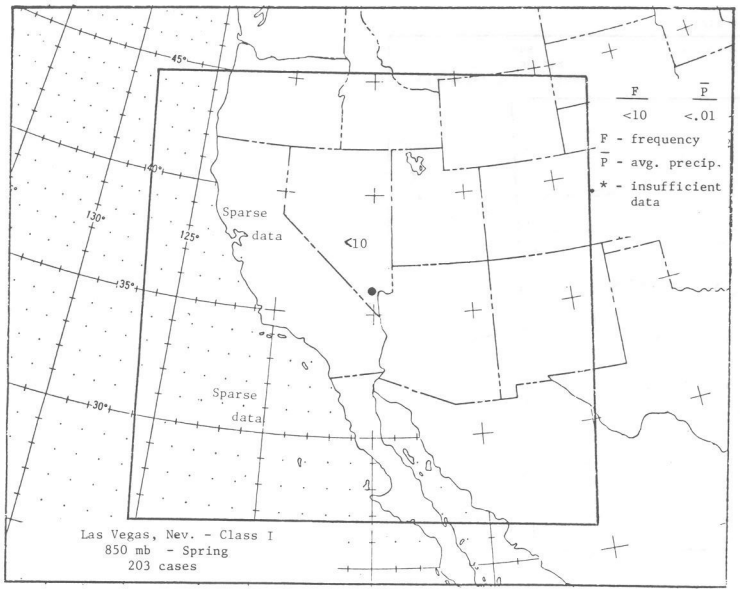



Chart 18 - Ia

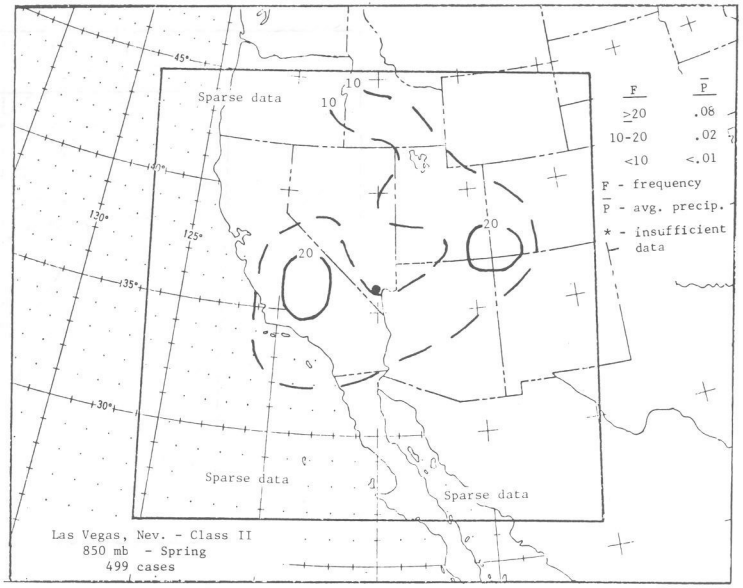



Chart 18 - IIa

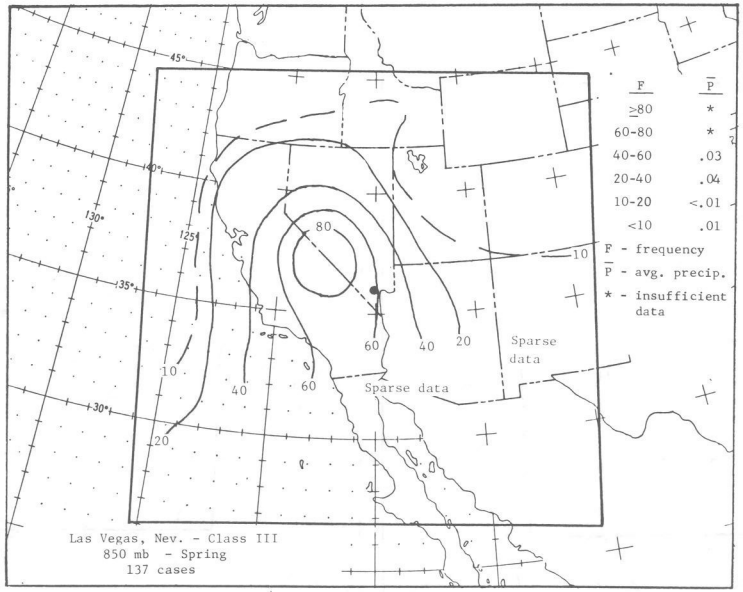



Chart 18 - IIIa

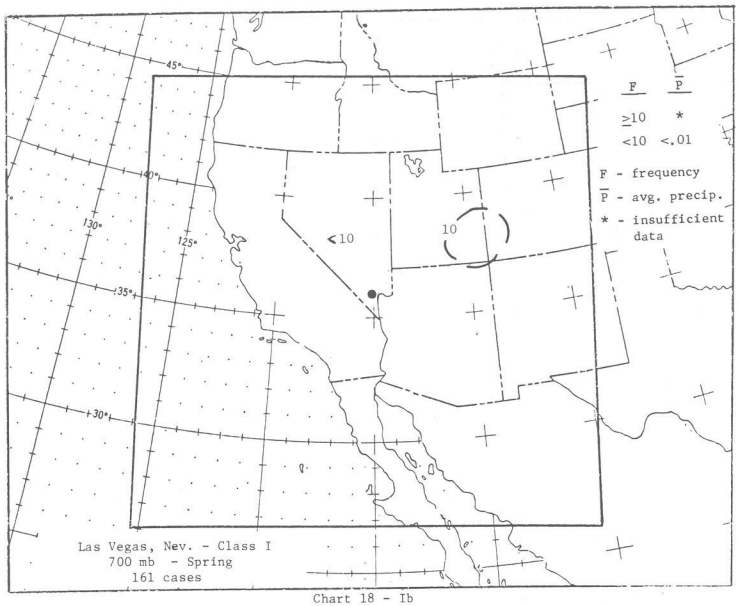



Chart 18 - Ib

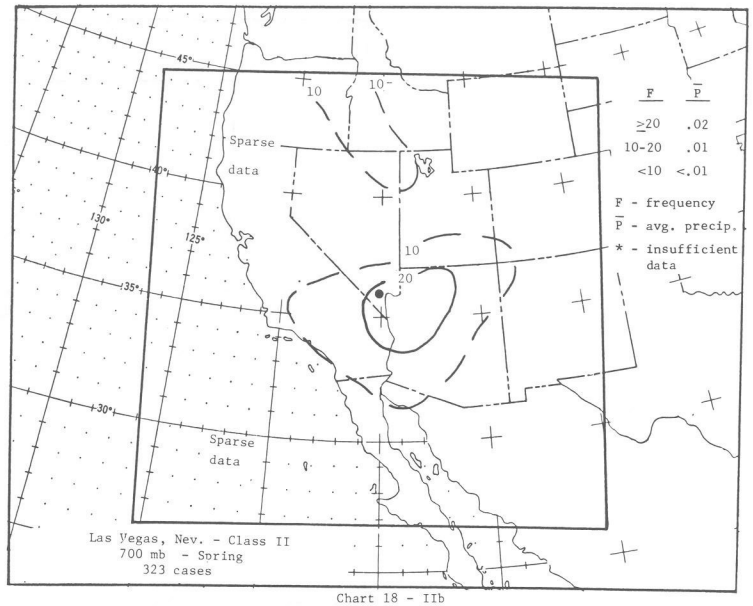



Chart 18 - IIb

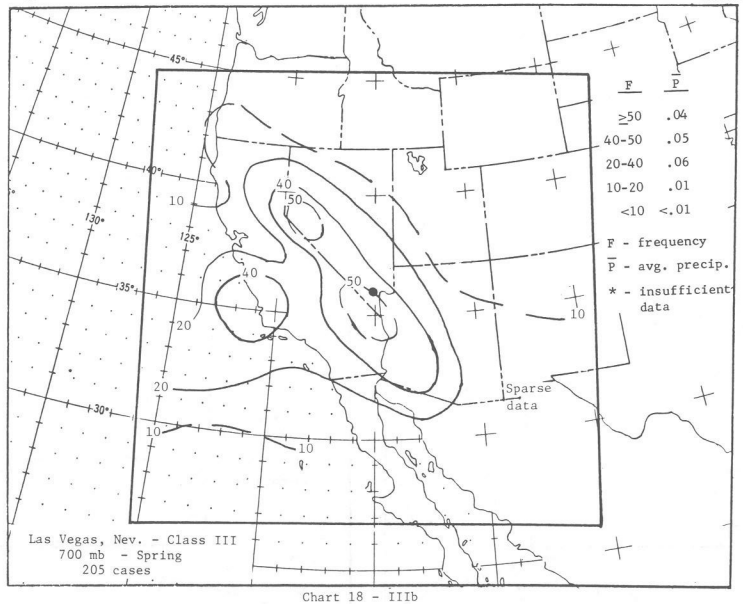



Chart 18 - IIIb

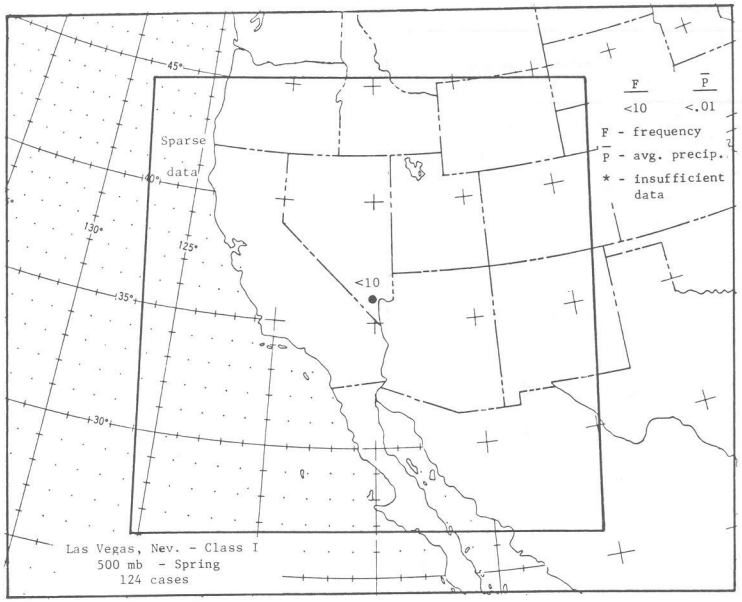



Chart 18 - Ic

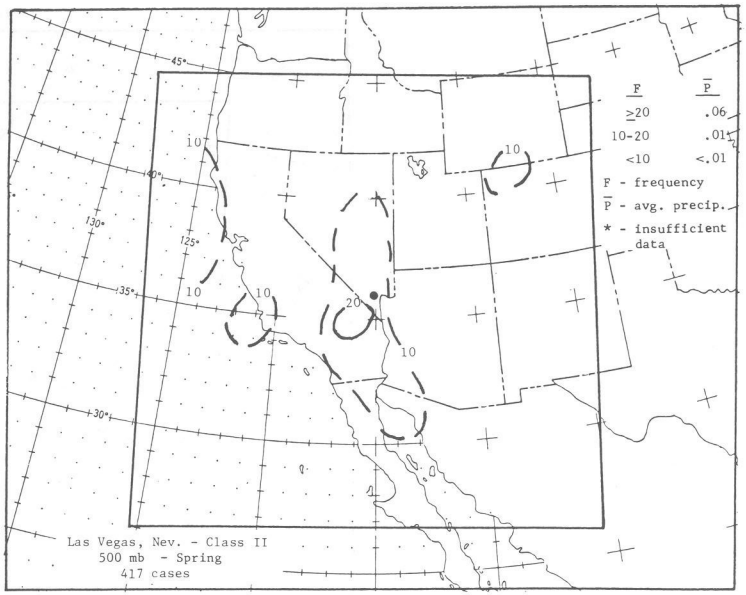



Chart 18 - IIc

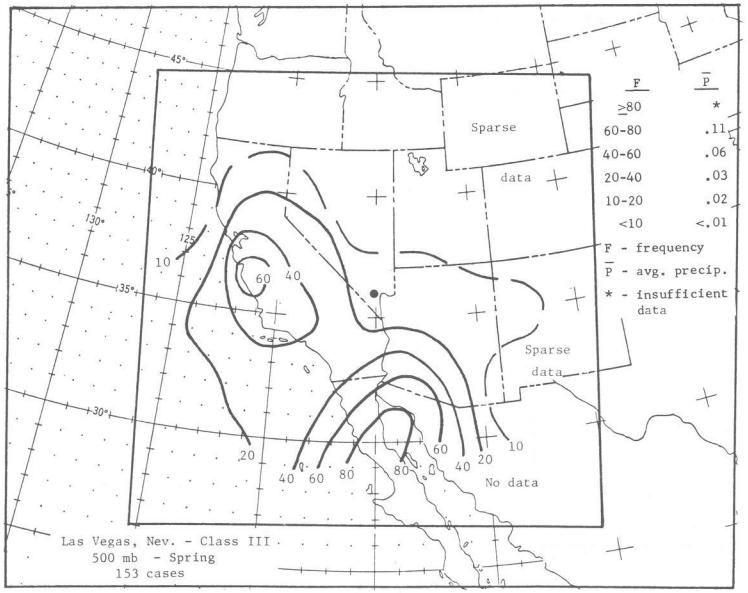



Chart 18 - IIIc

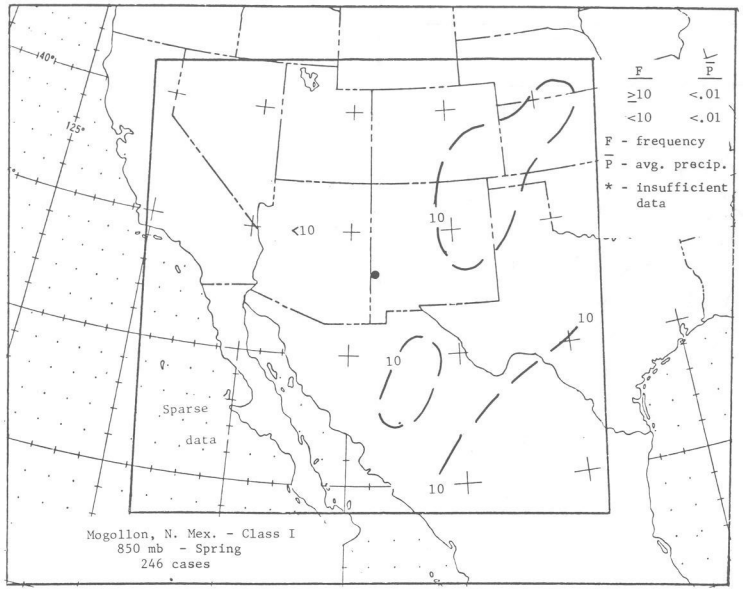



Chart 19 - Ia

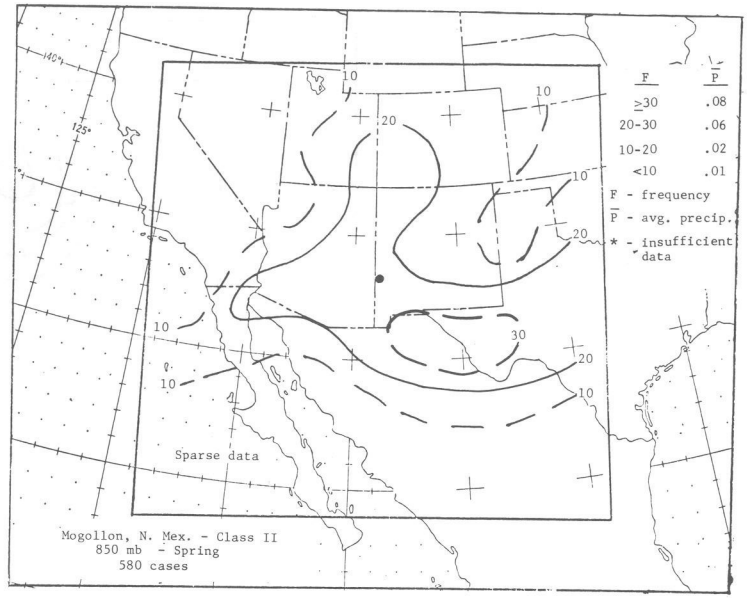



Chart 19 - IIa

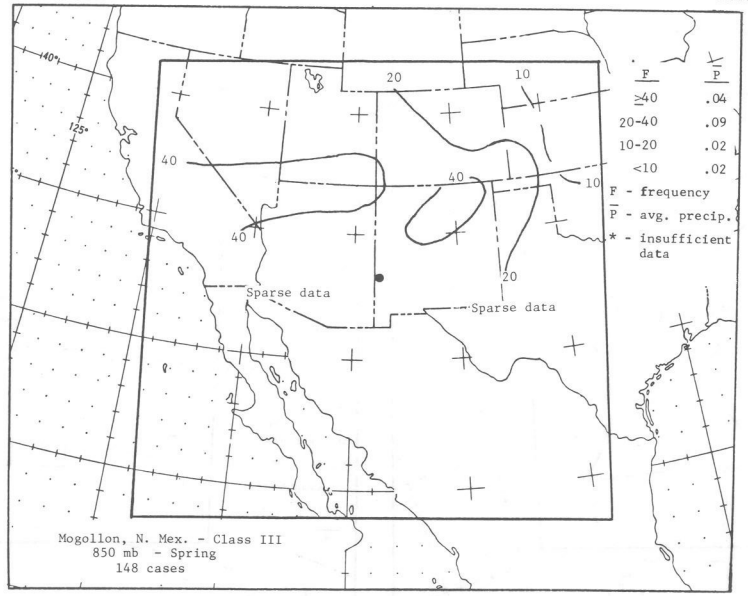



Chart 19 - IIIa

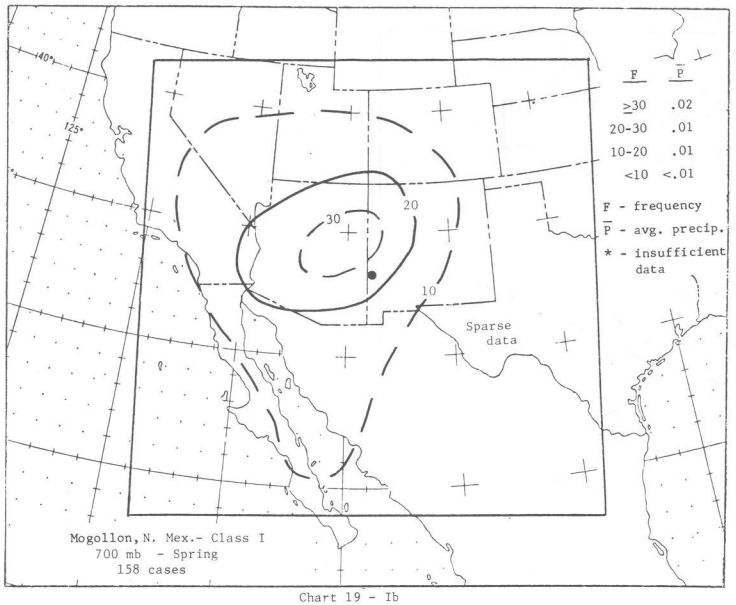



Chart 19 - Ib

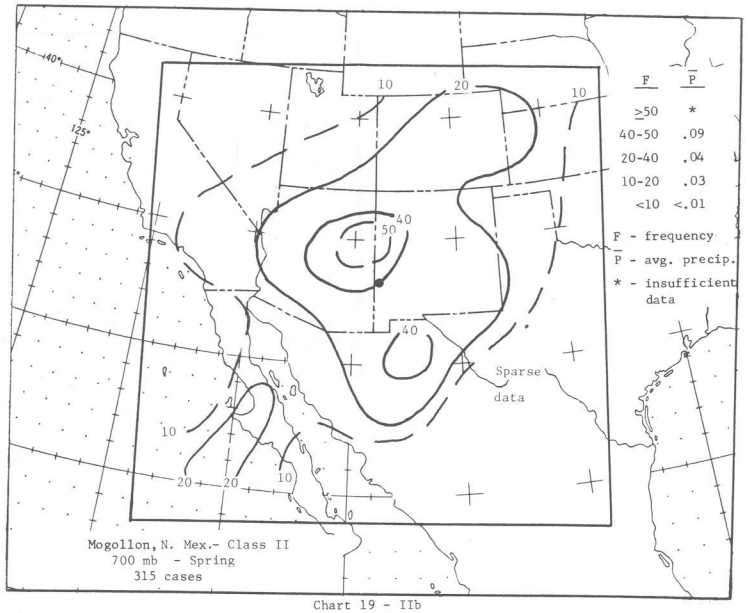



Chart 19 - IIb

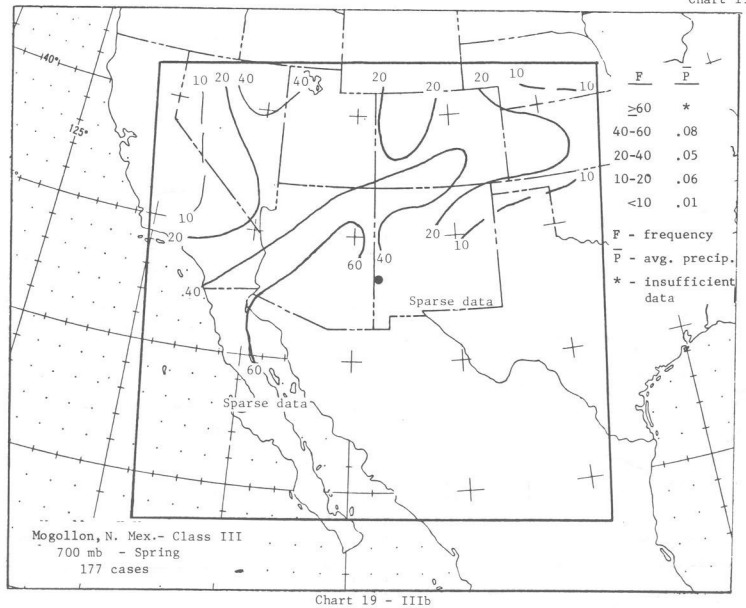



Chart 19 - IIIb

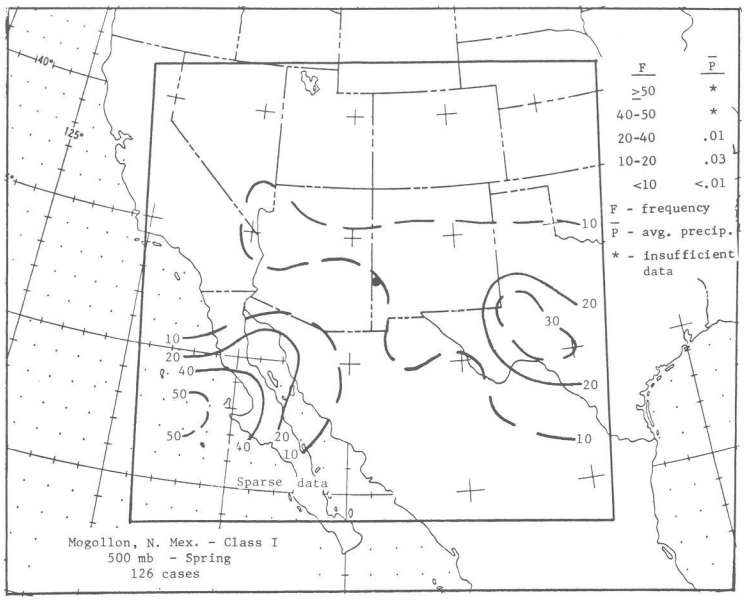



Chart 19 - Ic

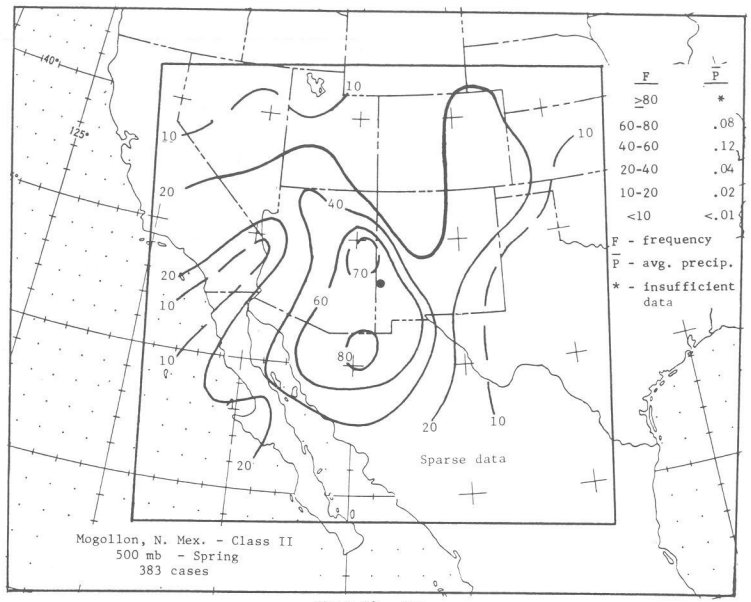



Chart 19 - IIc

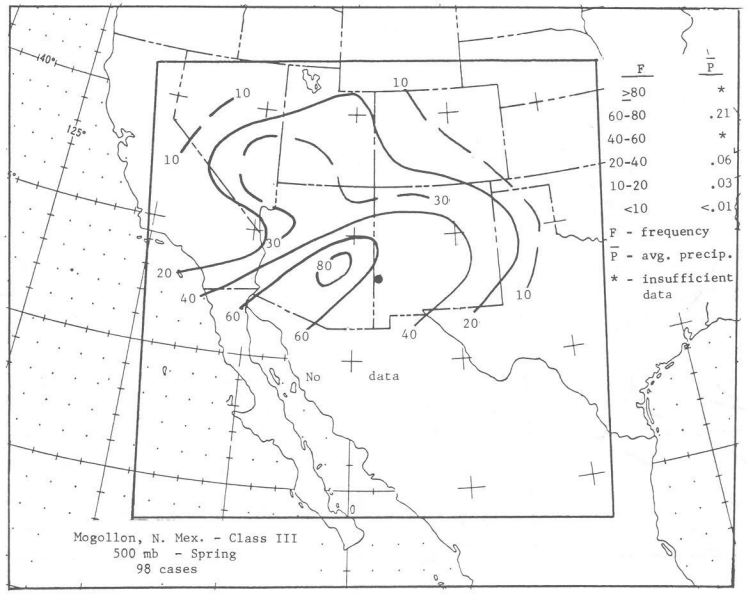



Chart 19 - IIIc

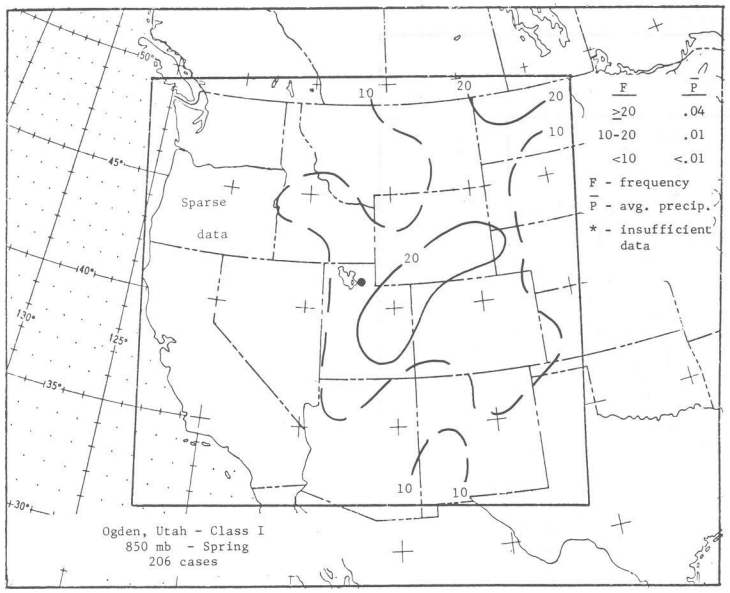



Chart 20 - Ia

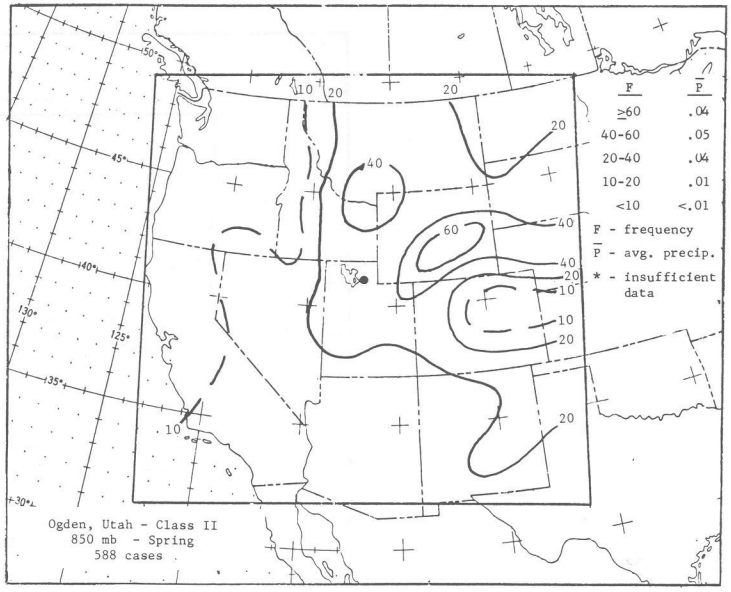



Chart 20 - IIa

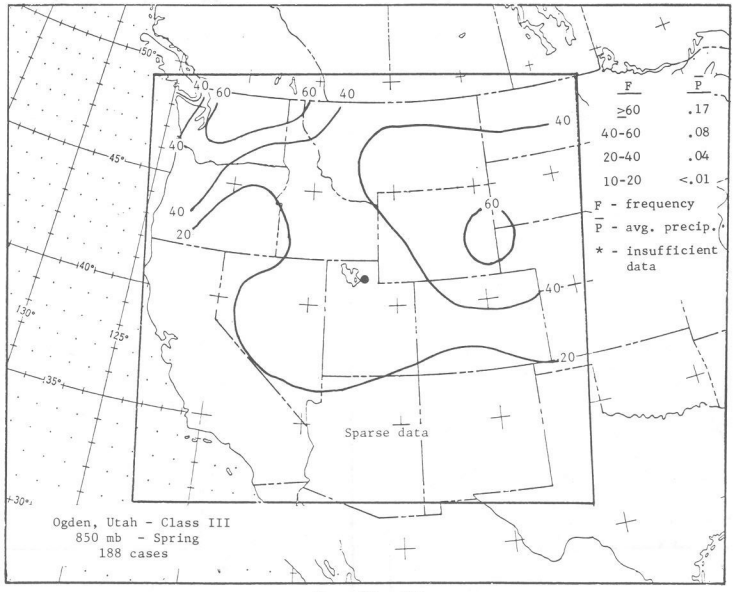



Chart 20 - IIIa

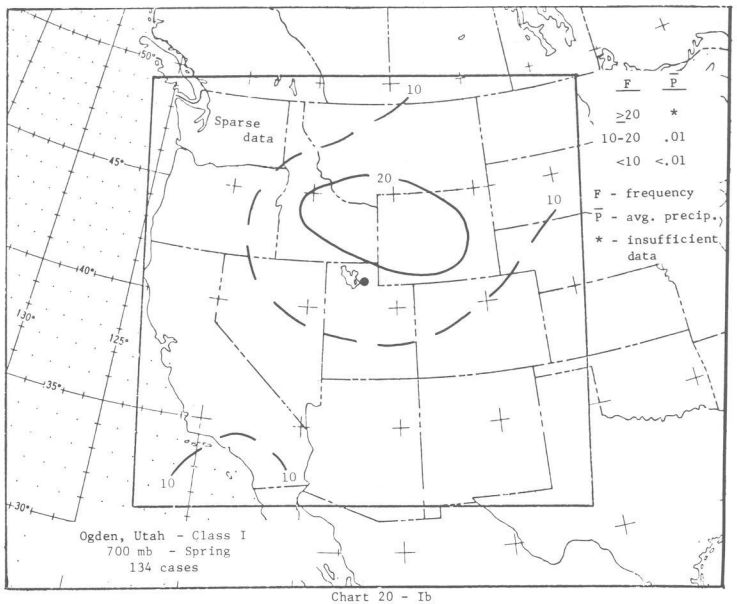



Chart 20 - Ib

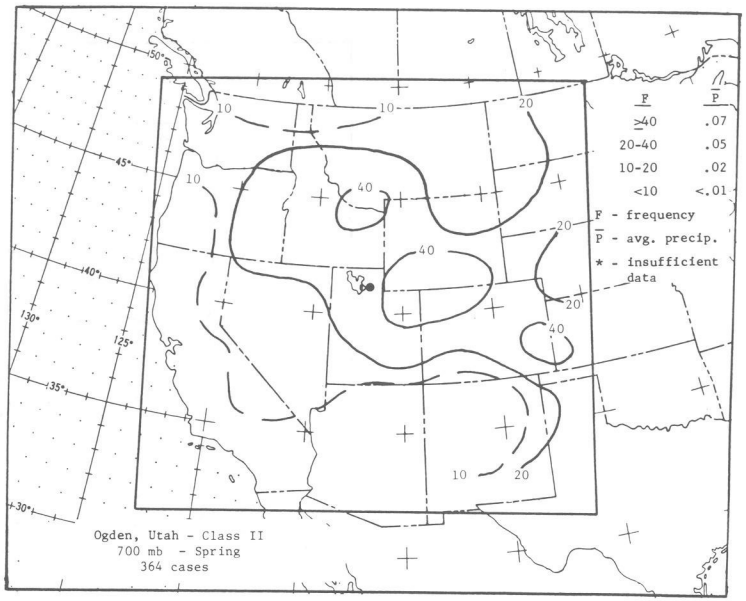



Chart 20 - IIb

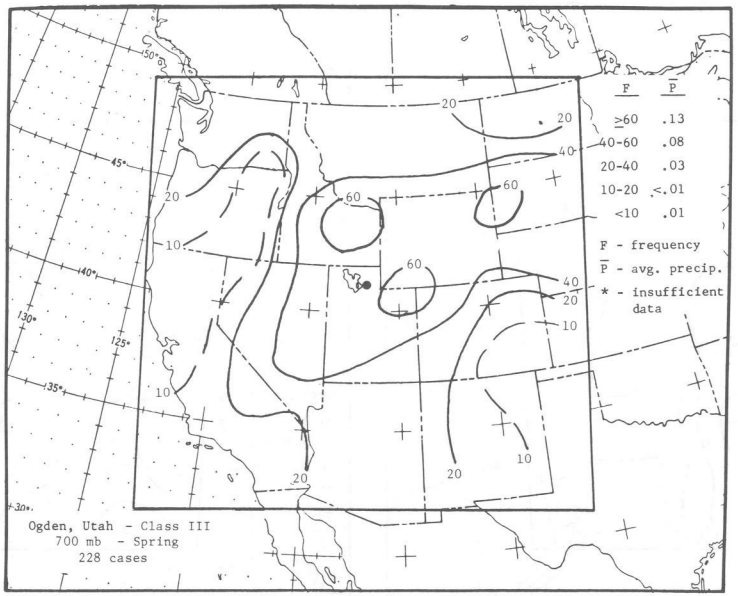



Chart 20 - IIIb

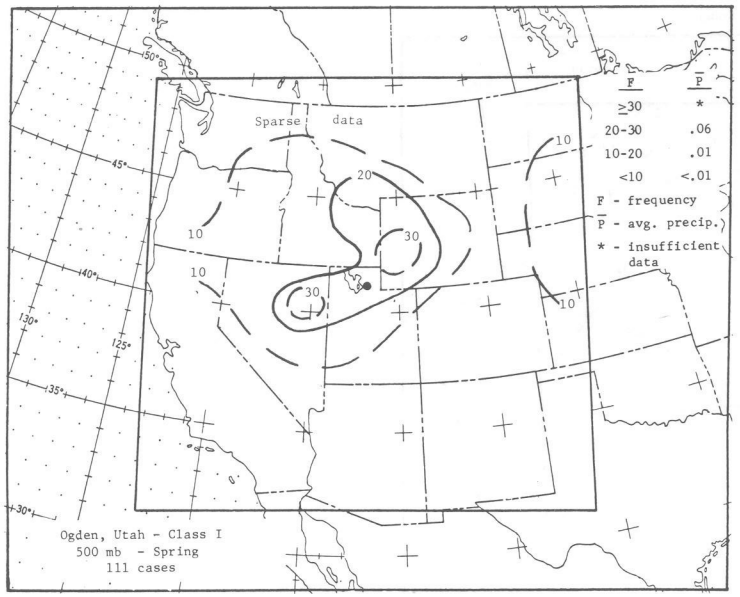



Chart 20 - Ic

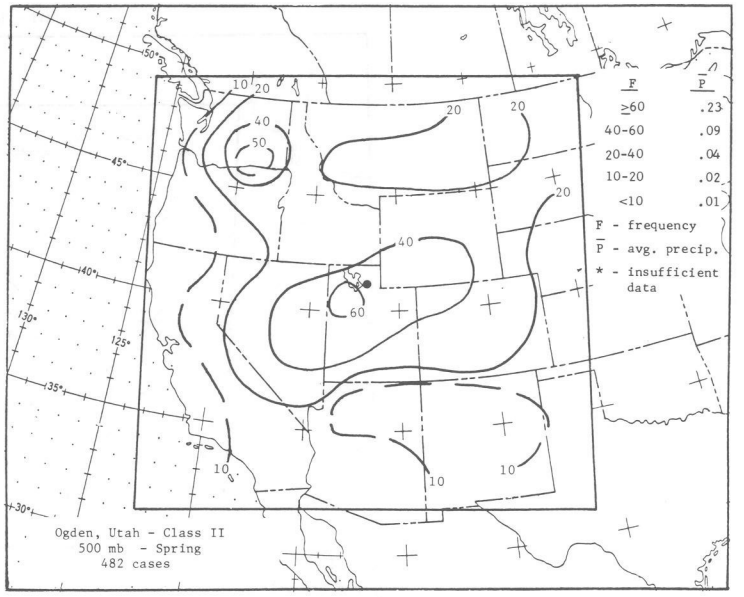



Chart 20 - IIc

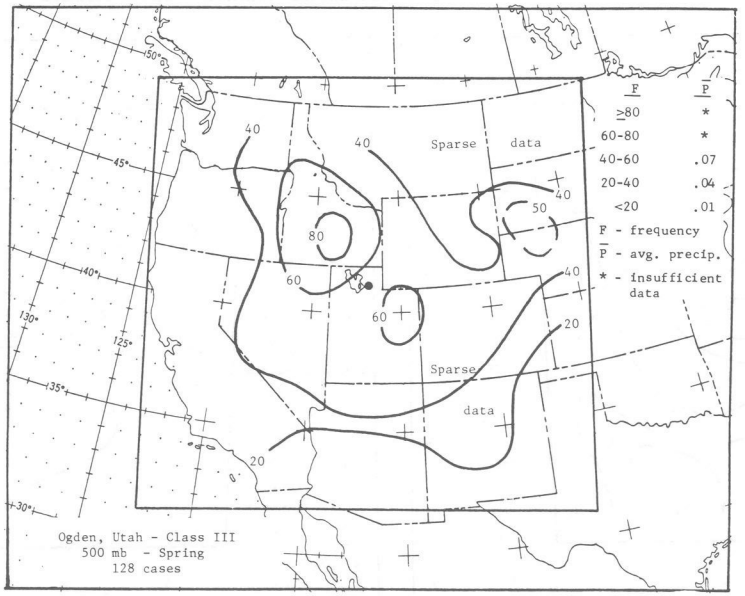



Chart 20 - IIIc

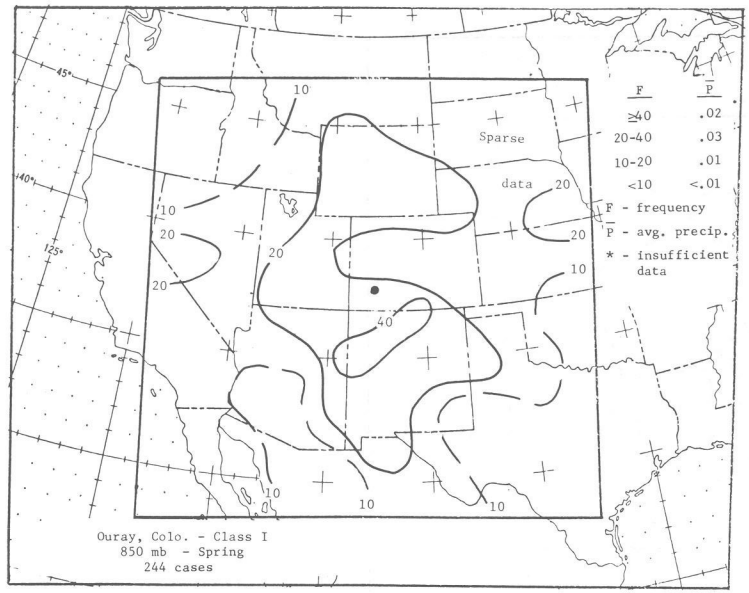



Chart 21 - Ia

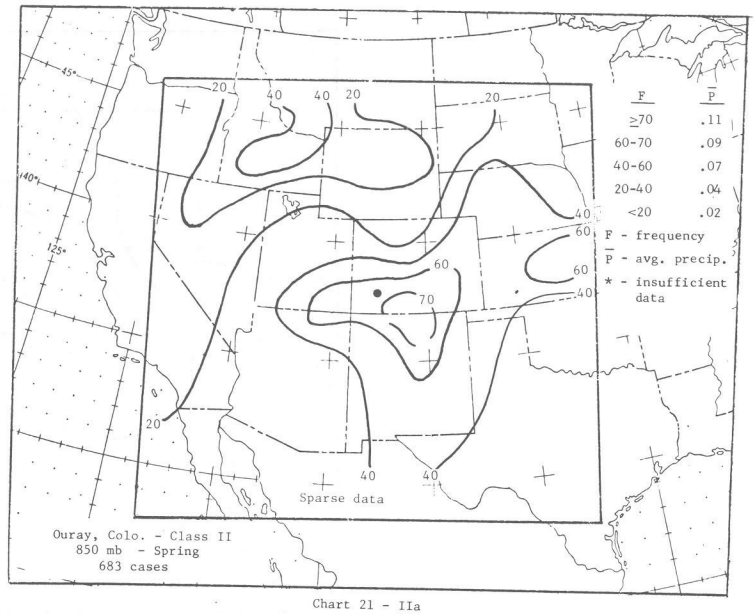



Chart 21 - IIa

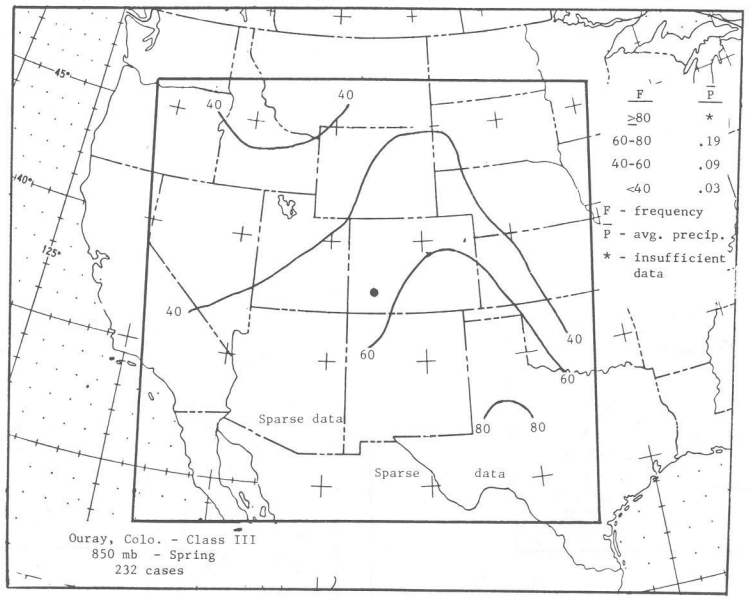



Chart 21 - IIIa

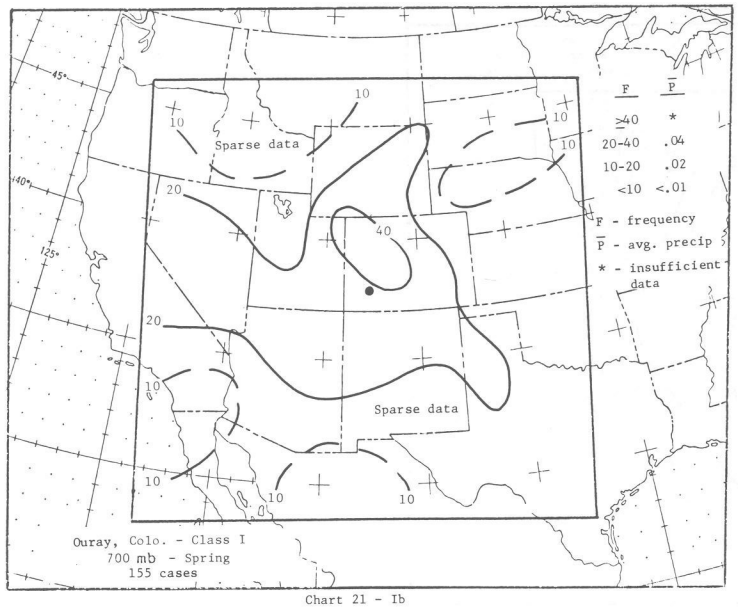



Chart 21 - Ib

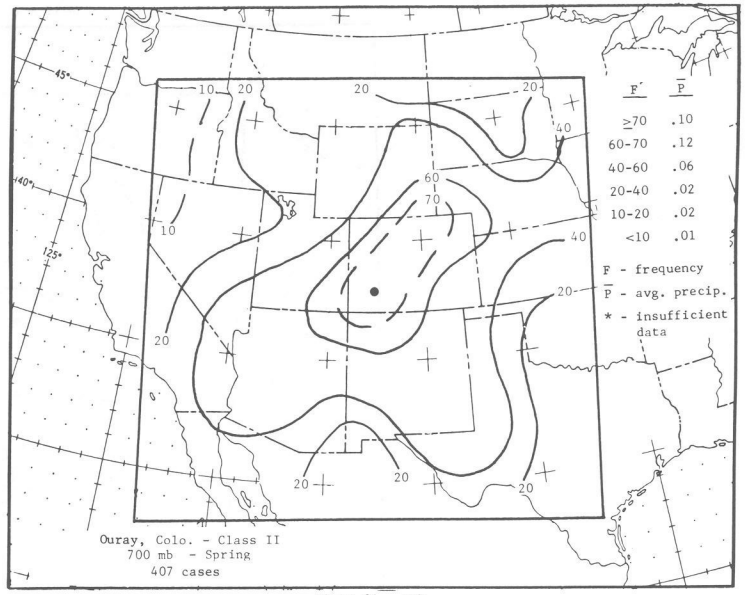



Chart 21 - IIb

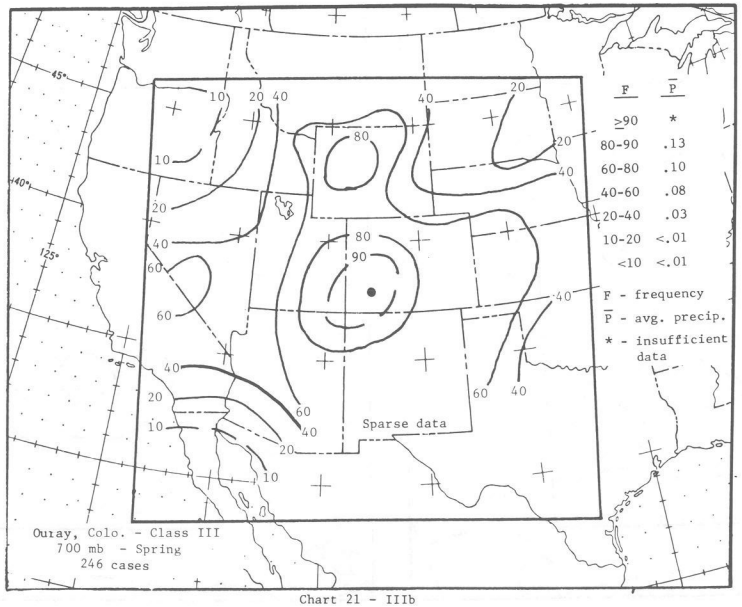



Chart 21 - IIIb

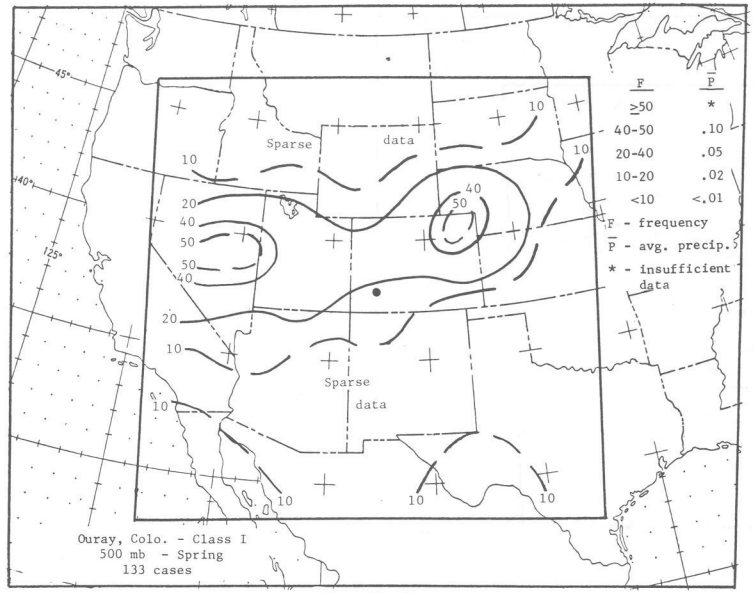



Chart 21 - Ic

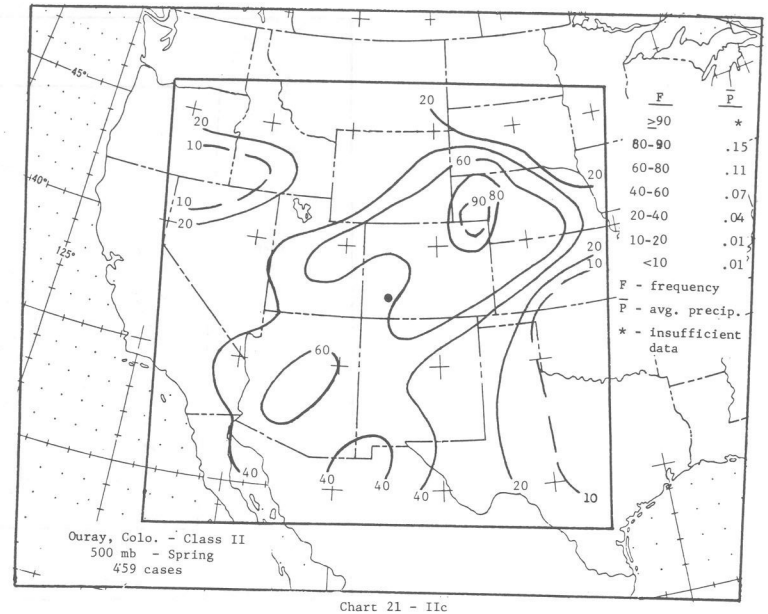



Chart 21 - IIc

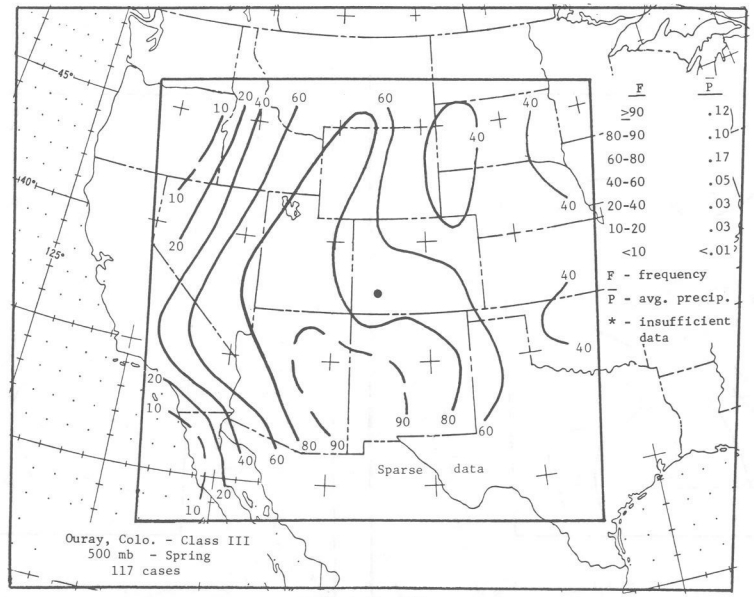



Chart 21 - IIIc

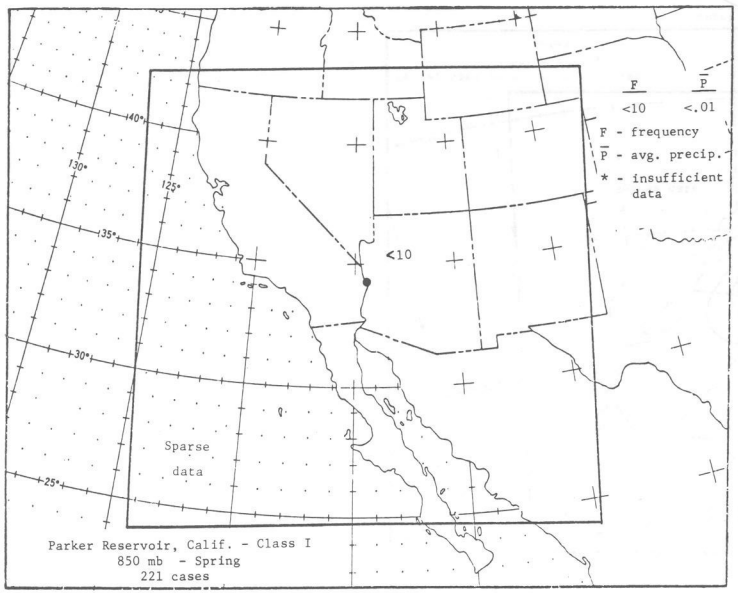



Chart 22 - Ia

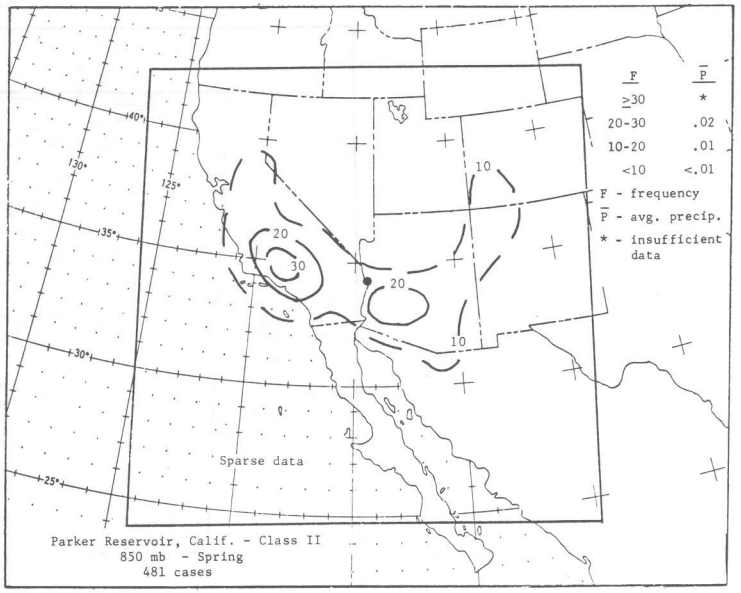



Chart 22 - IIa

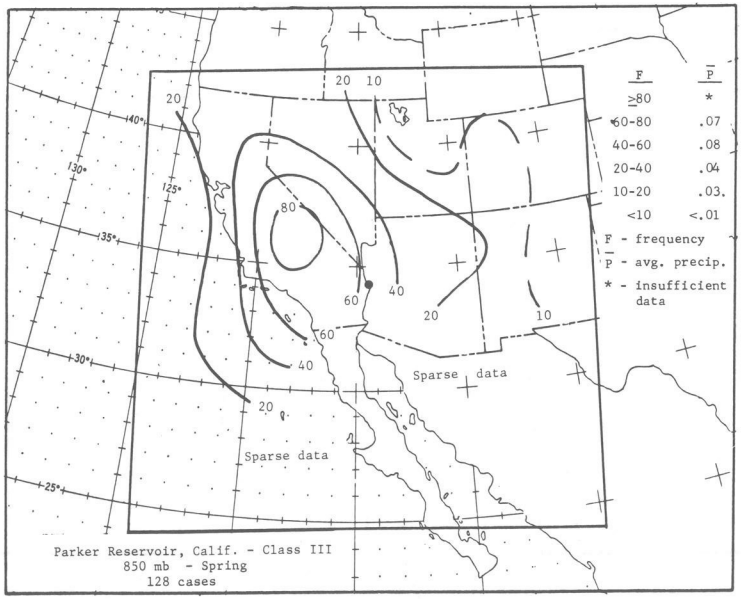



Chart 22 - IIIa

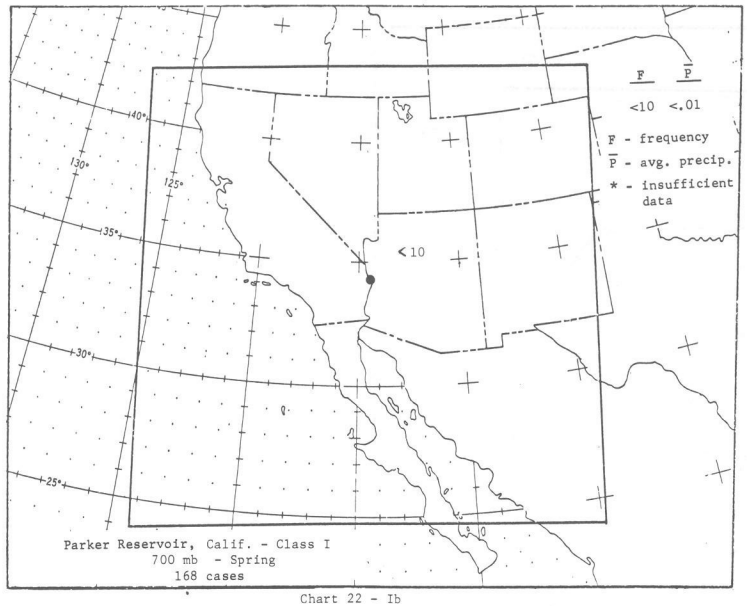



Chart 22 - Ib

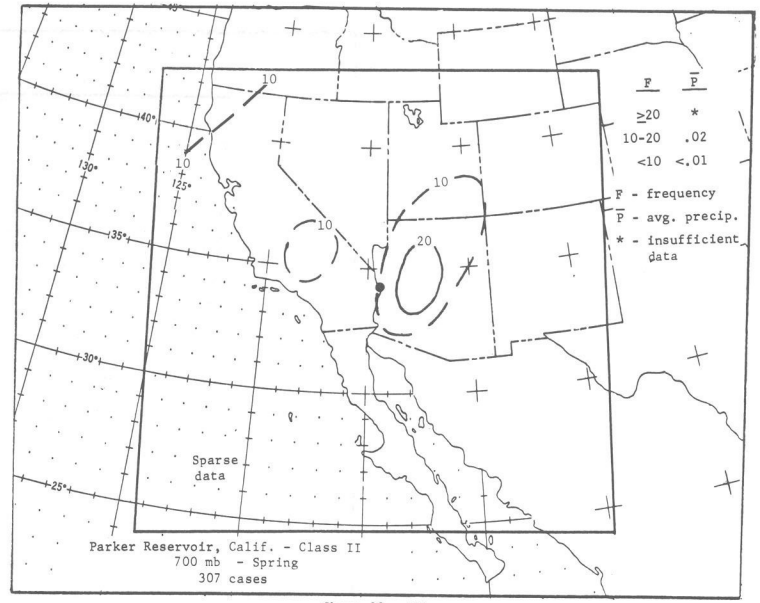



Chart 22 - IIb

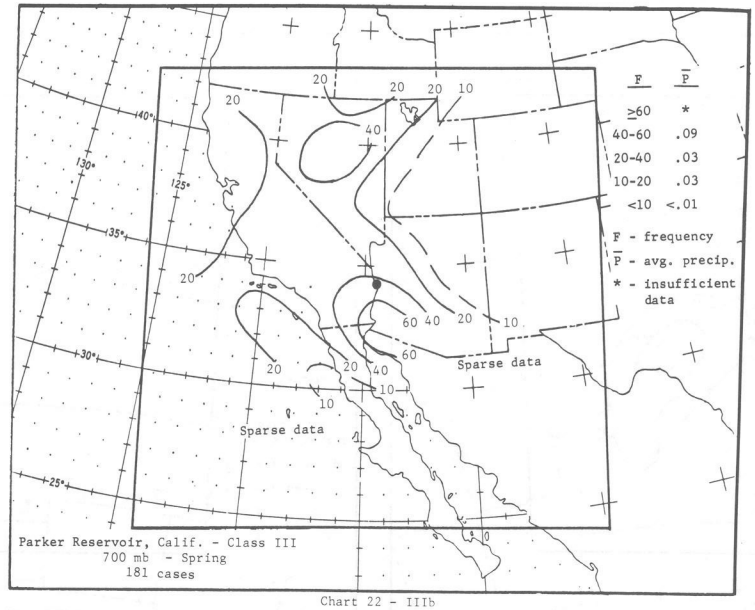



Chart 22 - IIIb

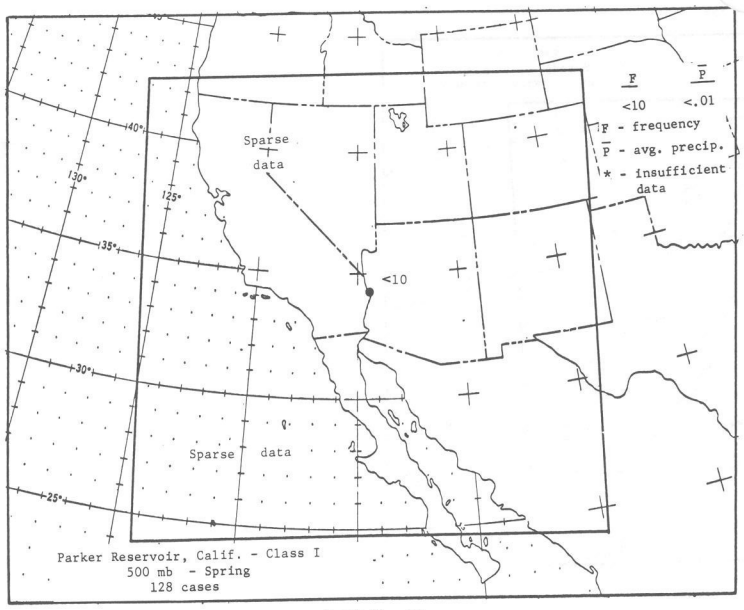



Chart 22 - Ic

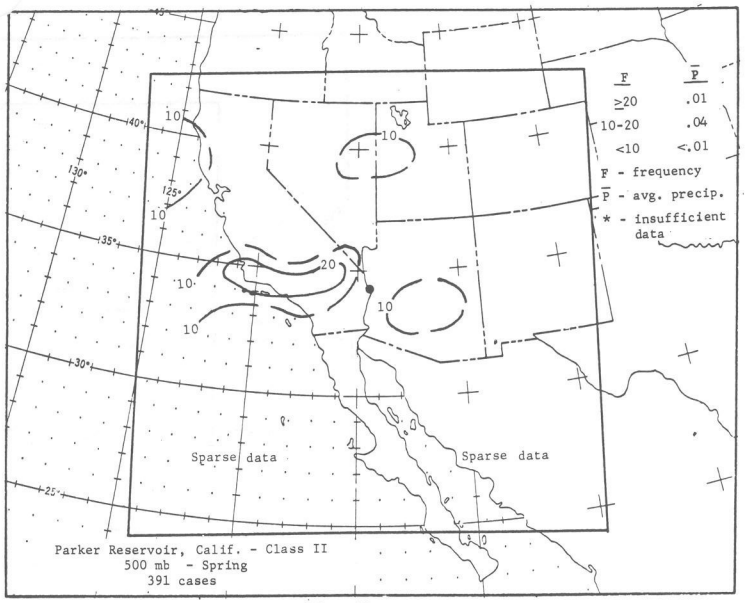



Chart 22 - IIc

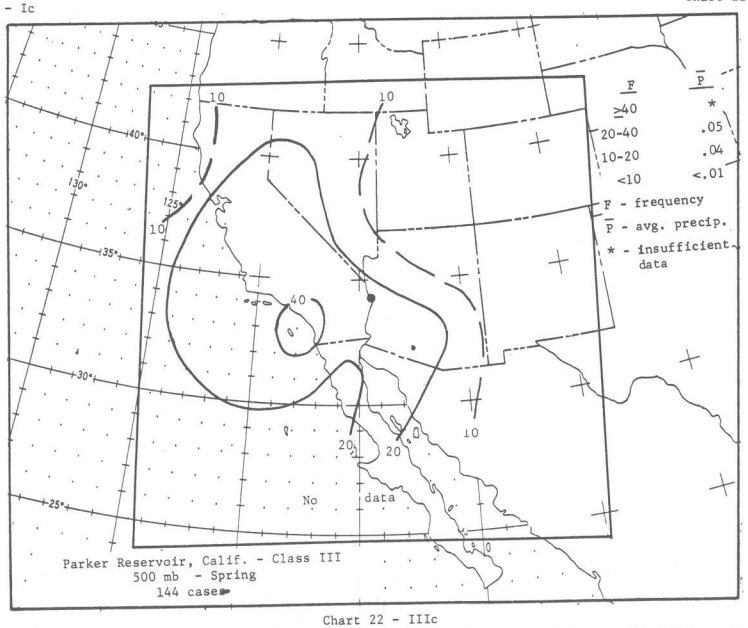



Chart 22 - IIIc

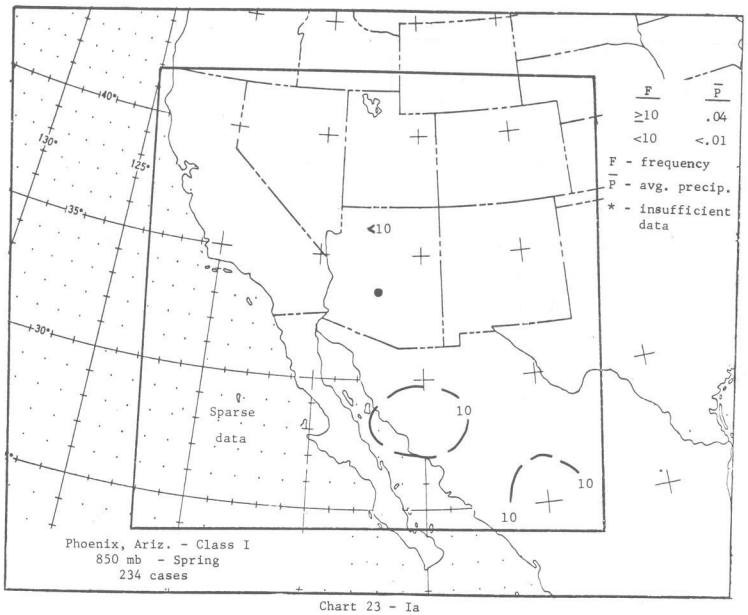



Chart 23 - Ia

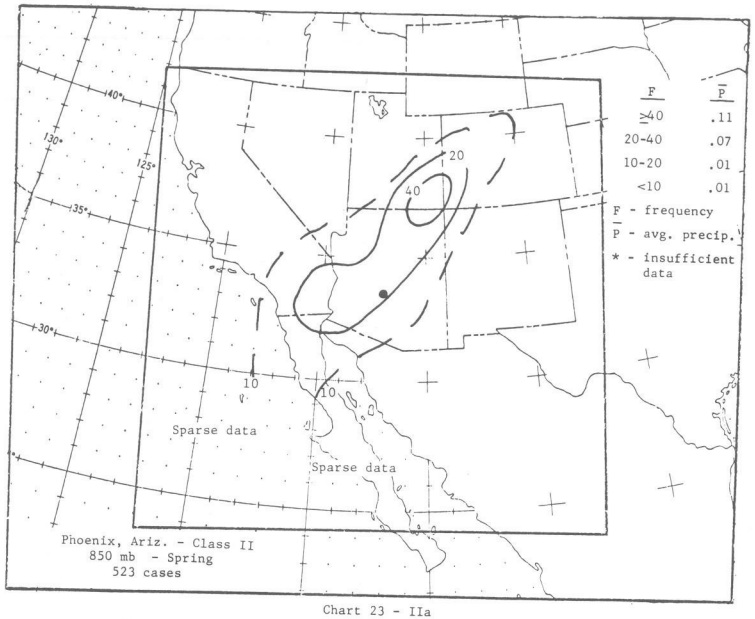



Chart 23 - IIa

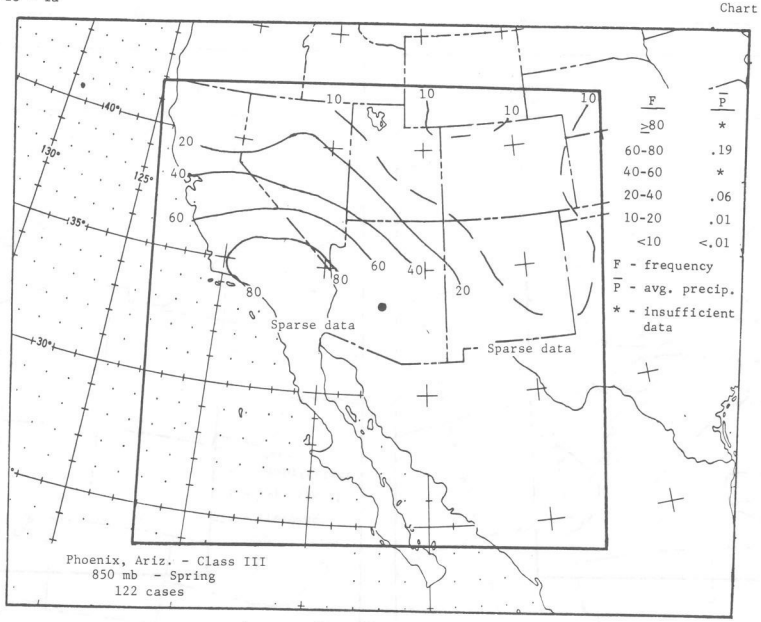



Chart 23 - IIIa

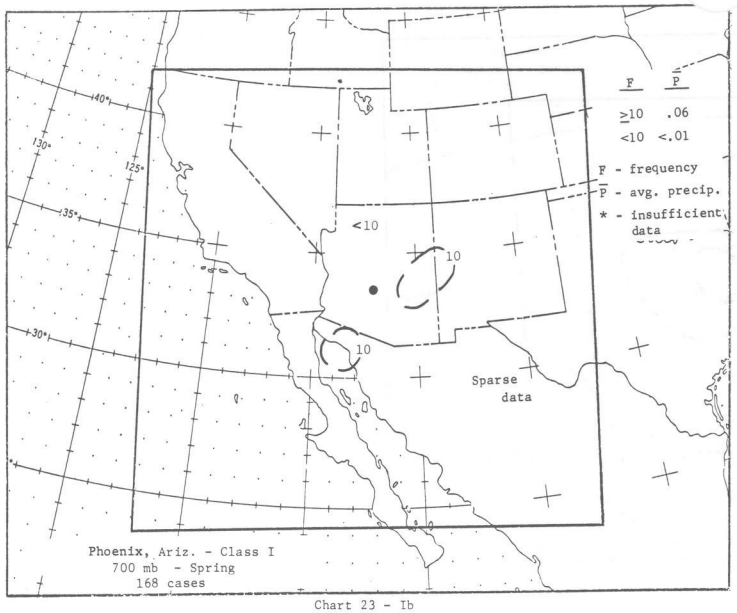



Chart 23 - Ib

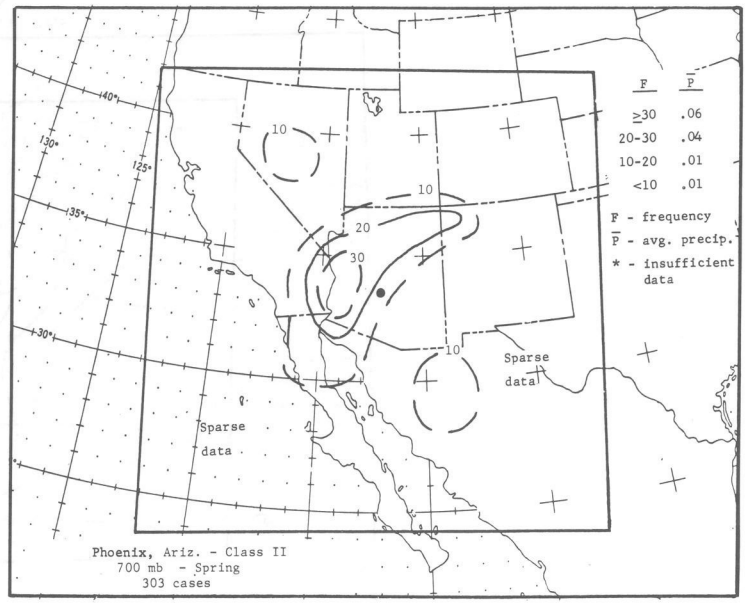



Chart 23 - IIb

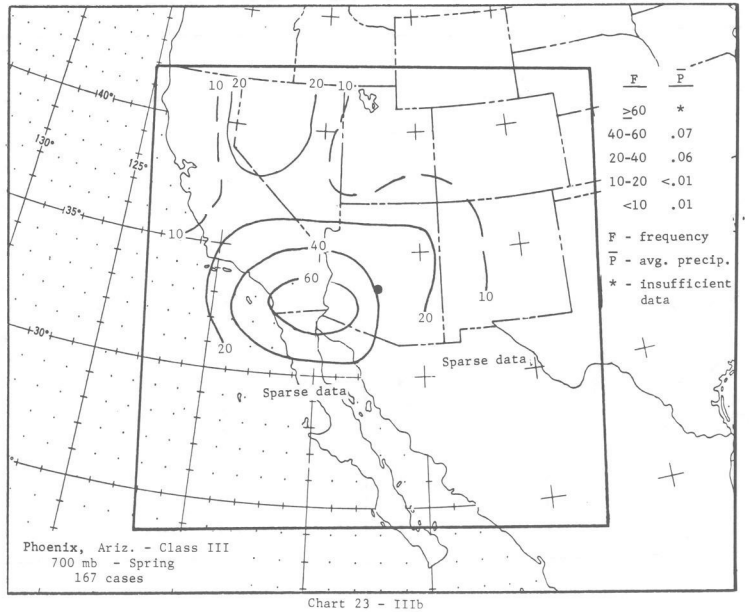



Chart 23 - IIIb

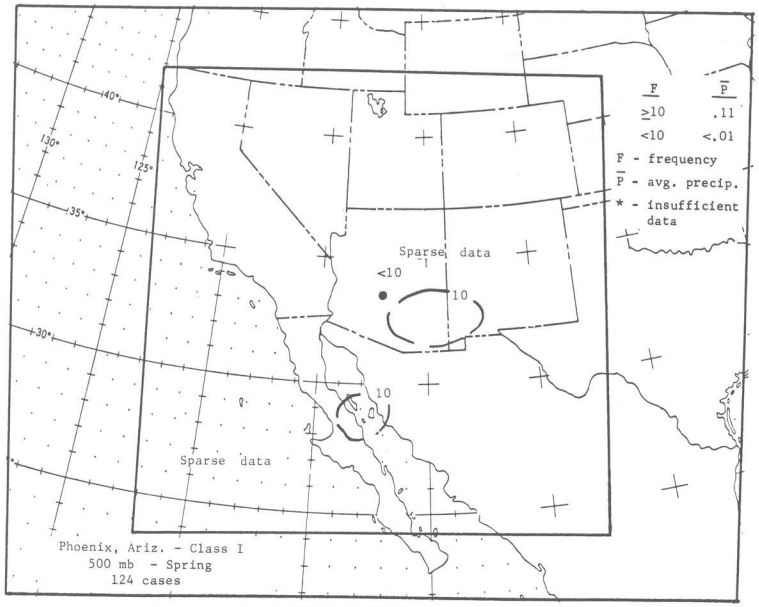



Chart 23 - Ic

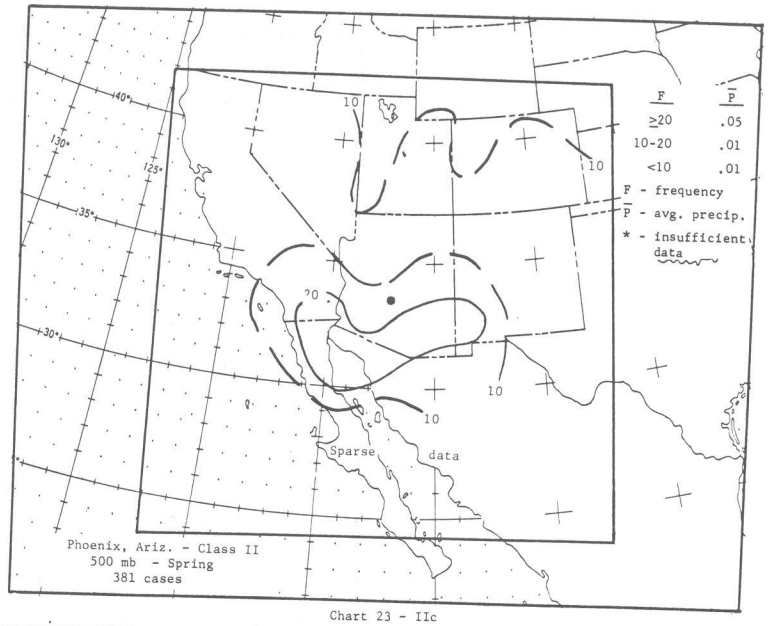



Chart 23 - IIc

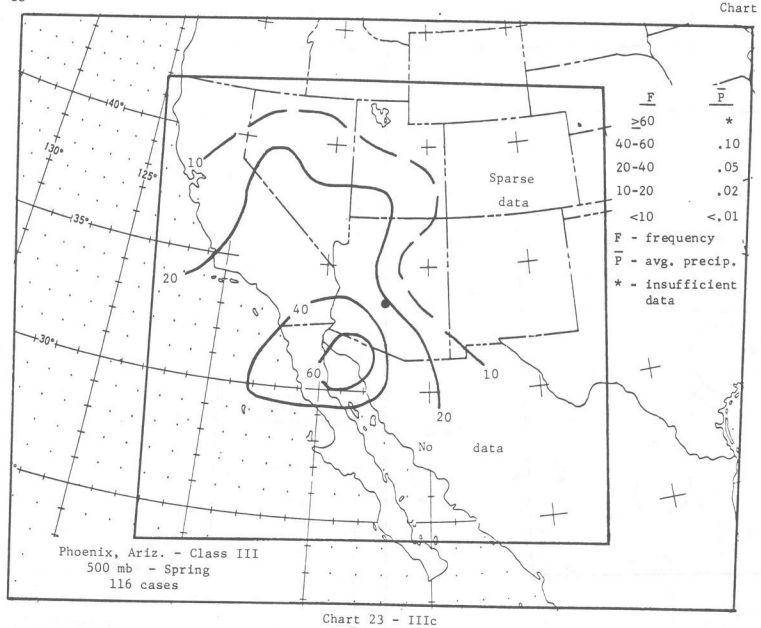



Chart 23 - IIIc

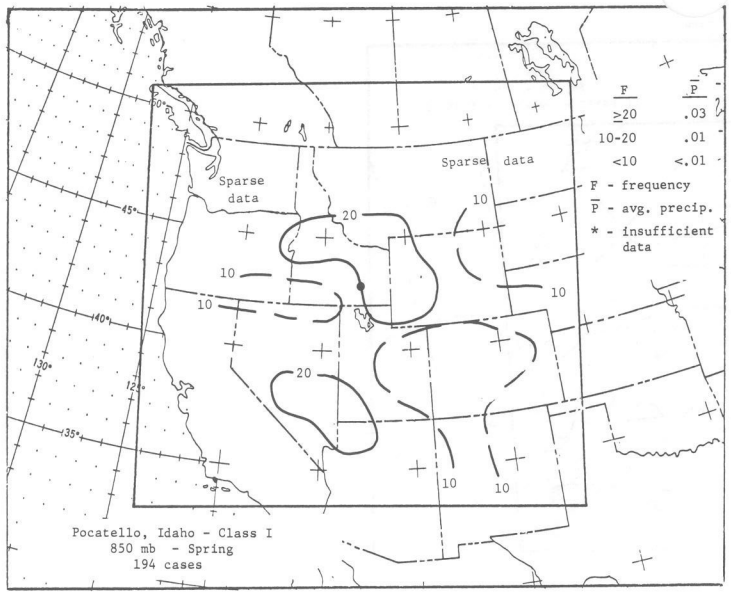



Chart 24 - Ia

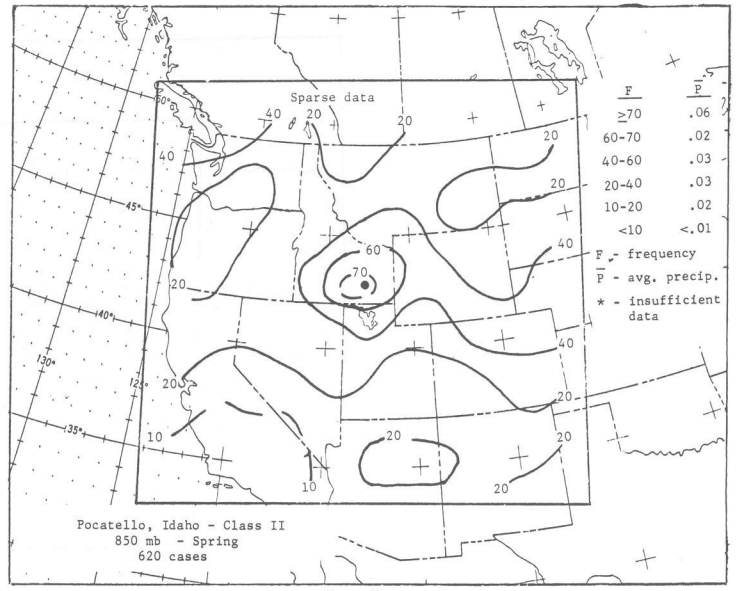



Chart 24 - IIa

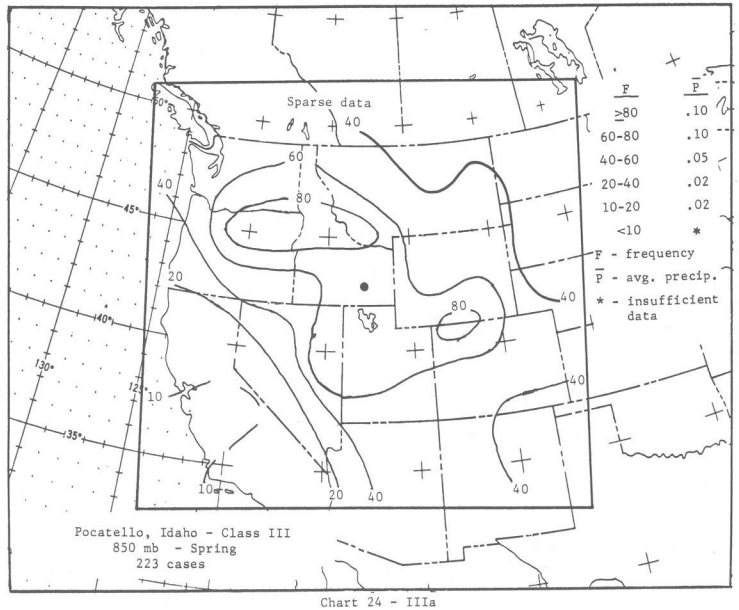



Chart 24 - IIIa

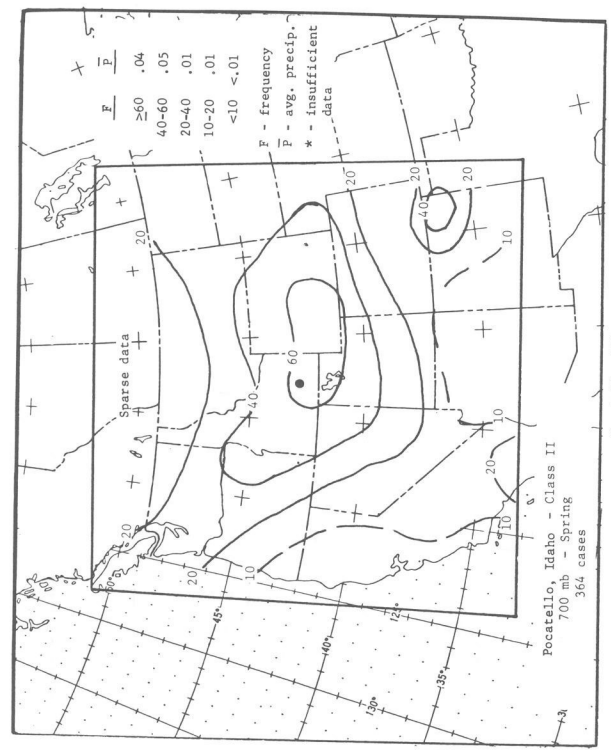



Chart 24 - IIb

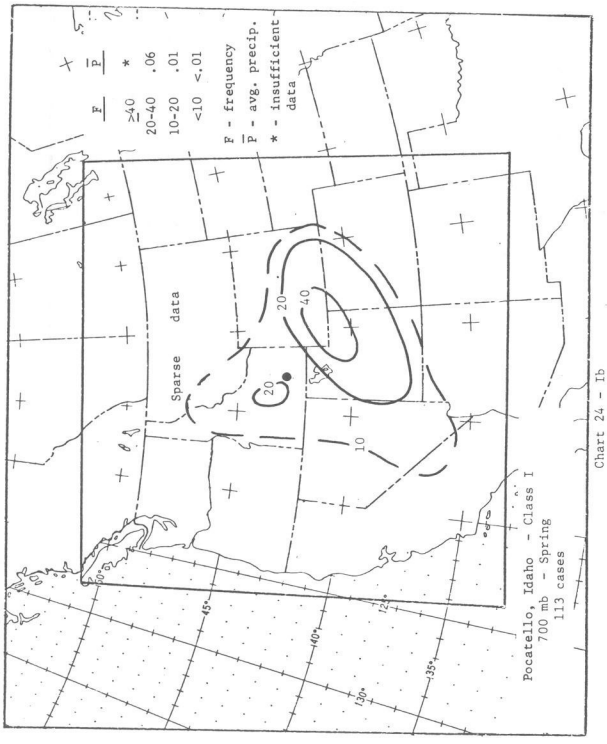



Chart 24 - Ib

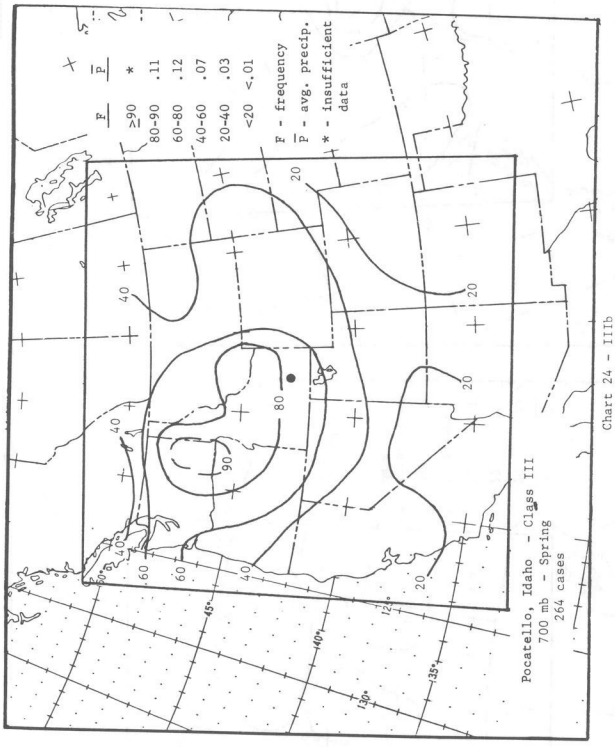



Chart 24 - IIIb

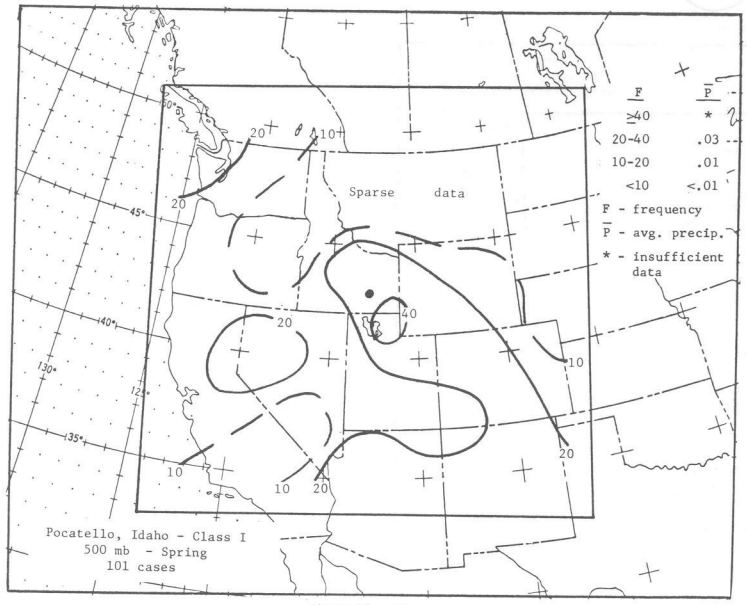



Chart 24 - Ic

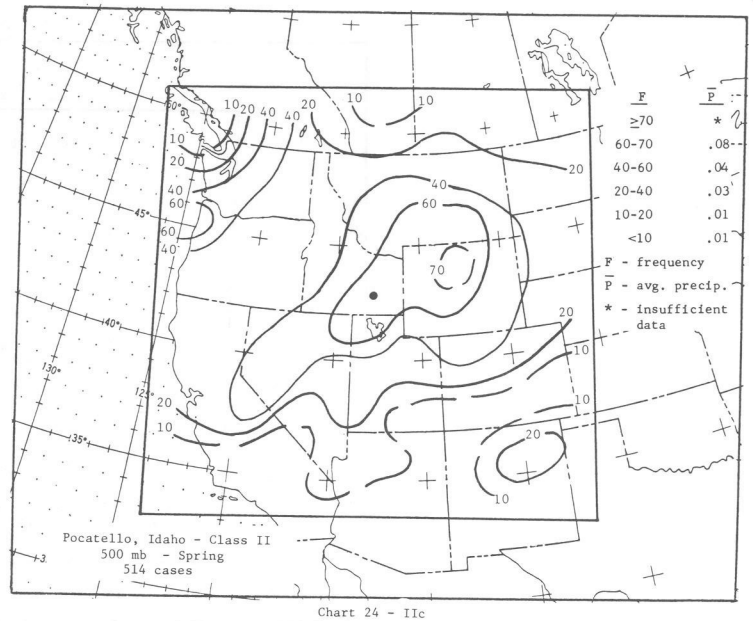



Chart 24 - IIc

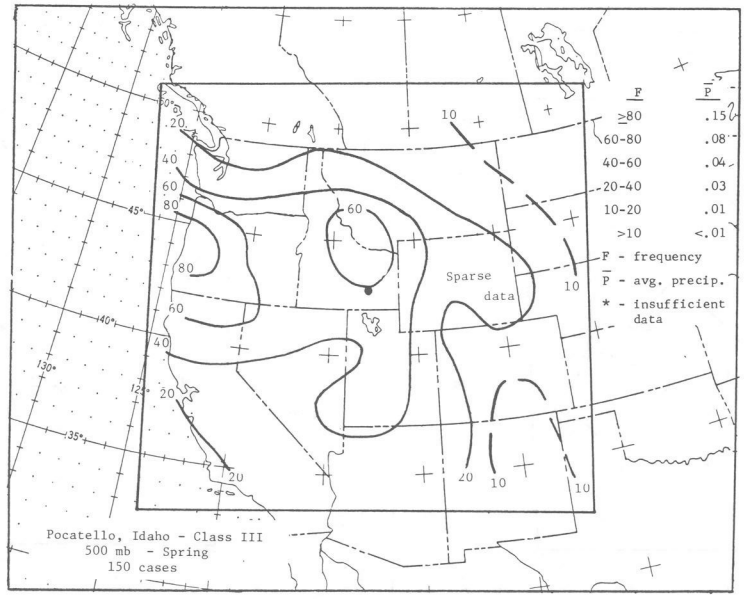



Chart 24 - IIIc

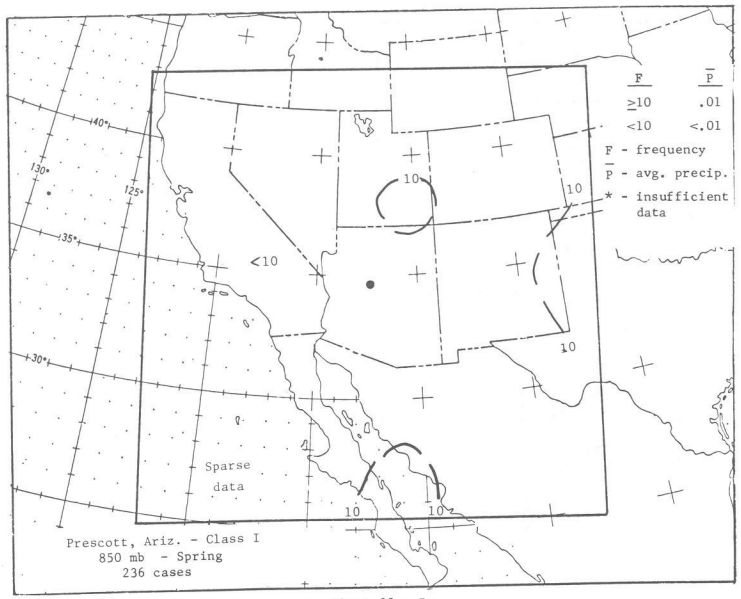



Chart 25 - Ia

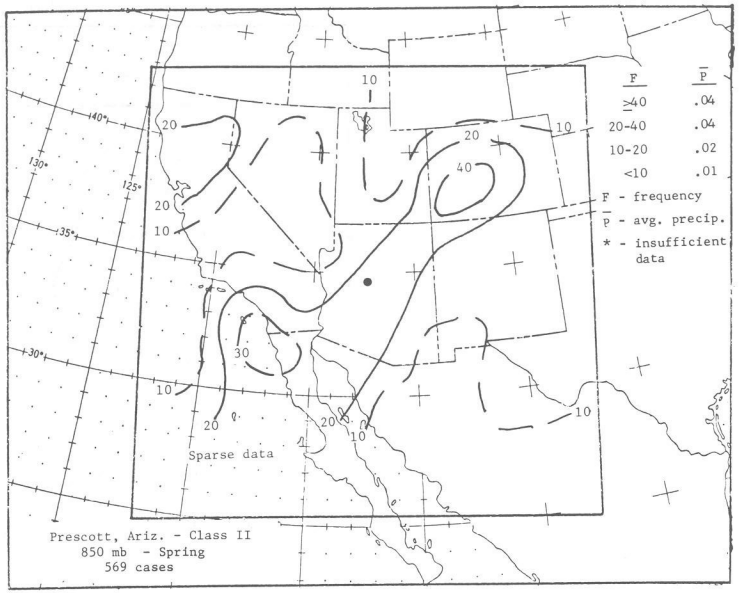



Chart 25 - IIa

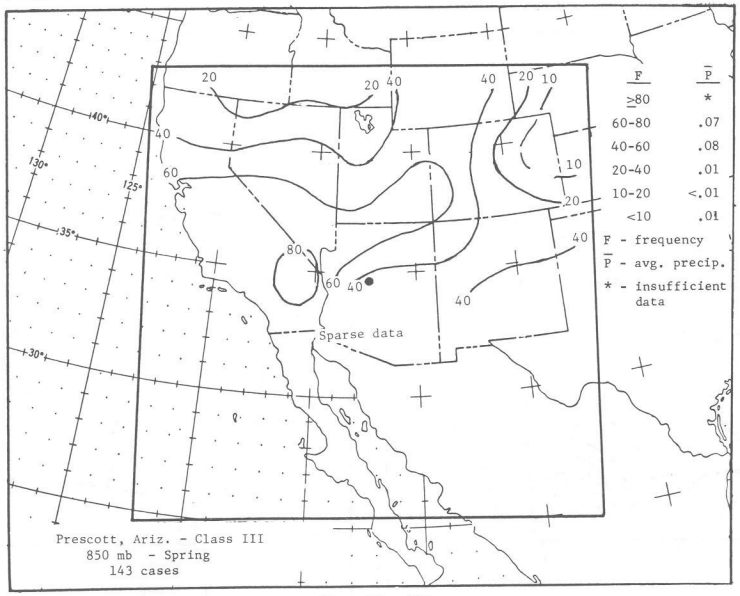



Chart 25 - IIIa

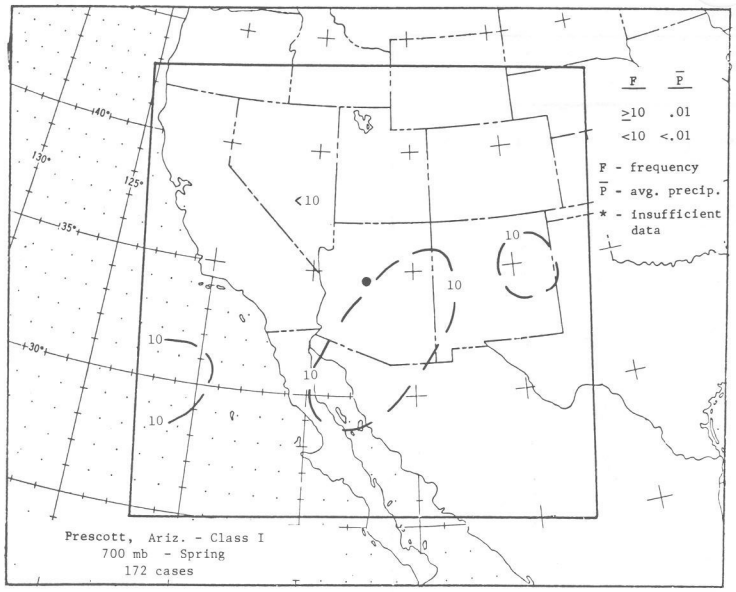



Chart 25 - Ib

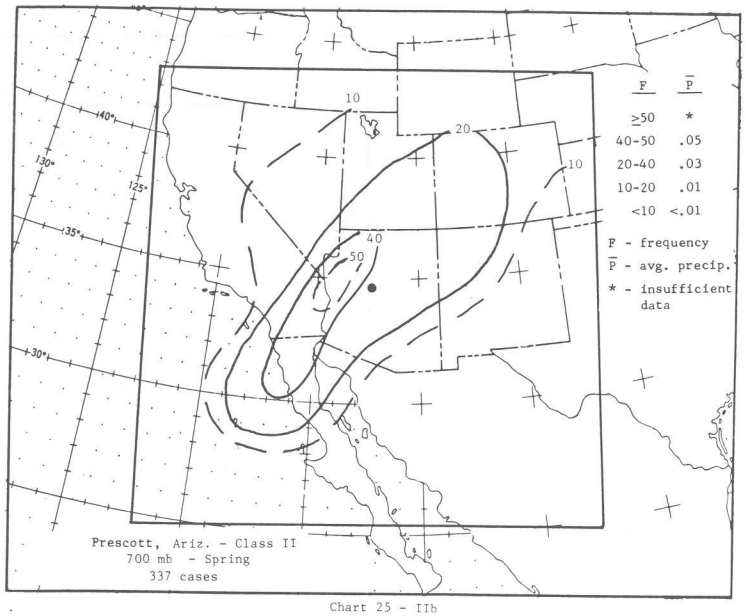



Chart 25 - IIb

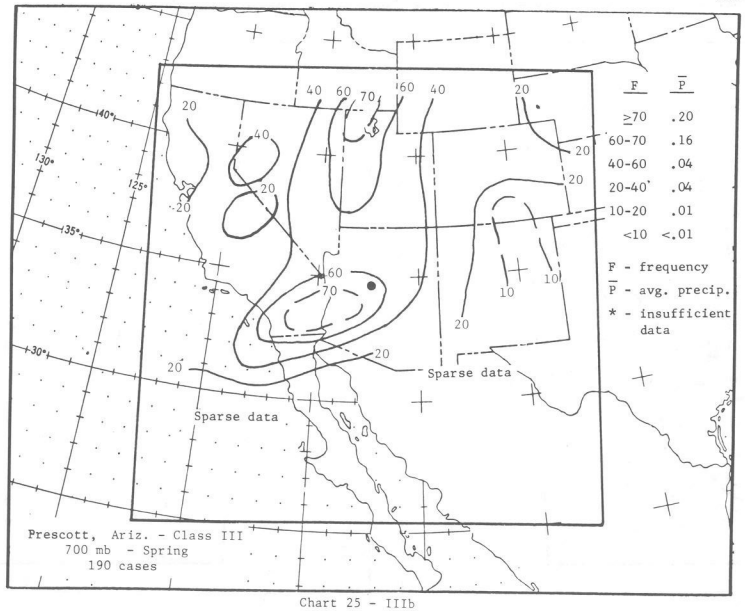



Chart 25 - IIIb

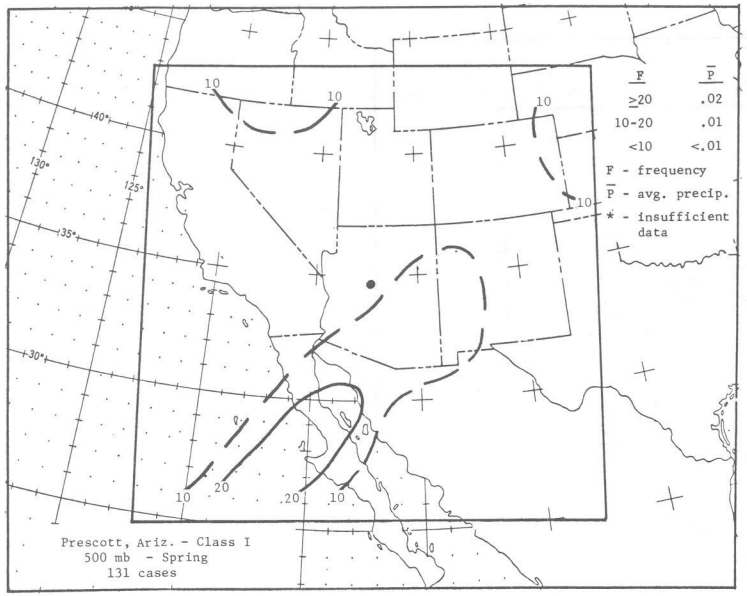



Chart 25 - Ic

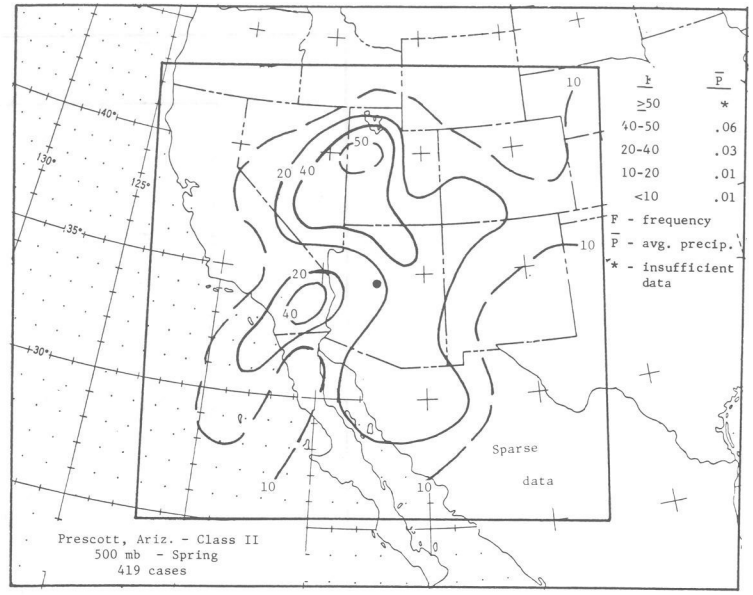



Chart 25 - IIc

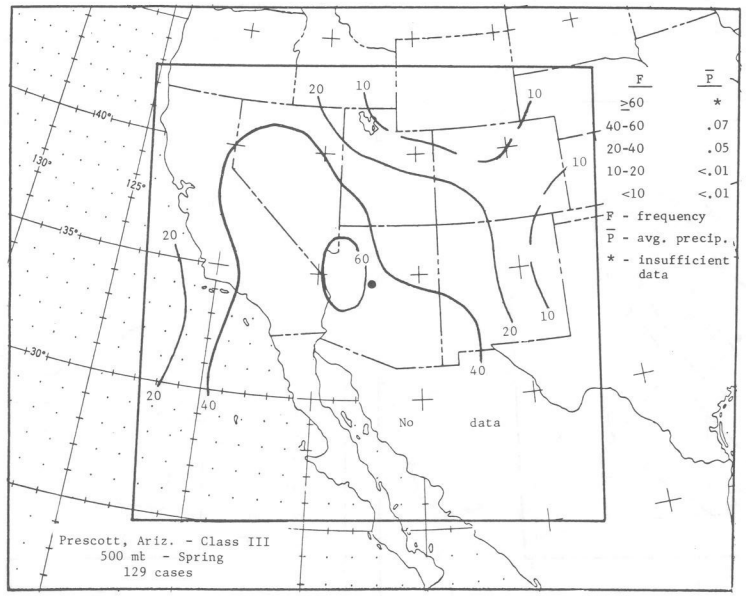



Chart 25 - IIIc

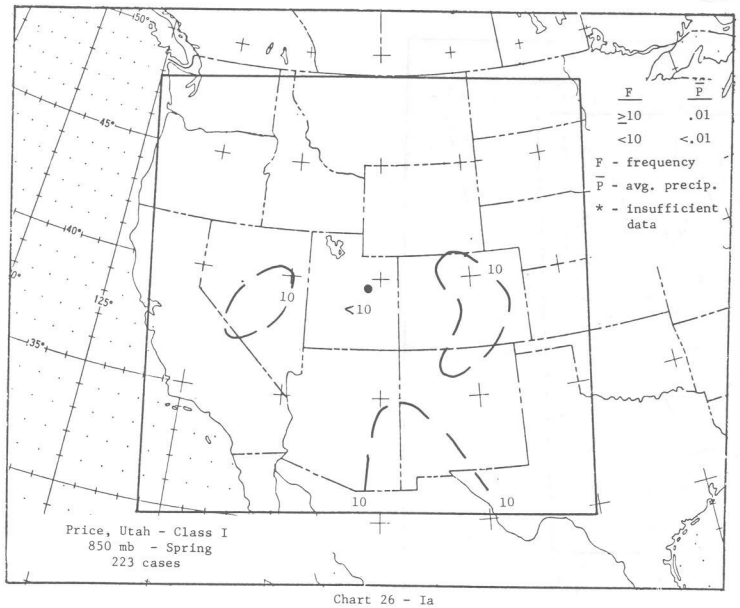



Chart 26 - Ia

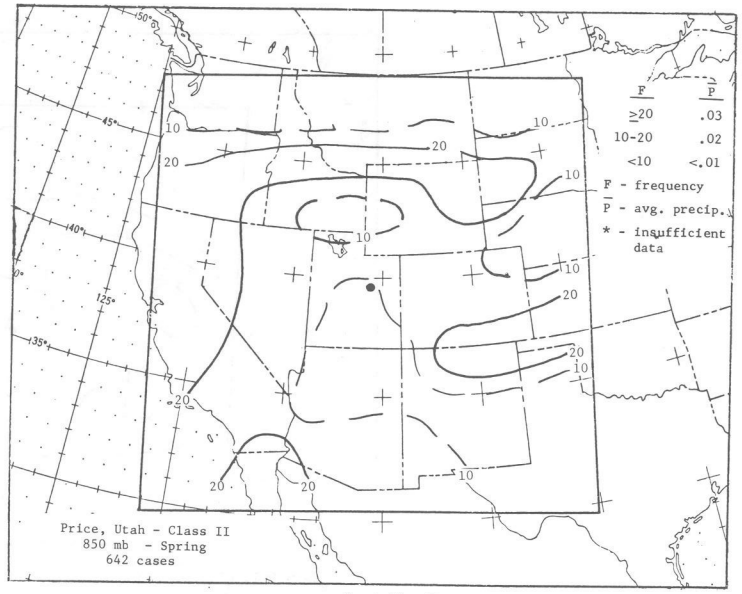



Chart 26 - IIa

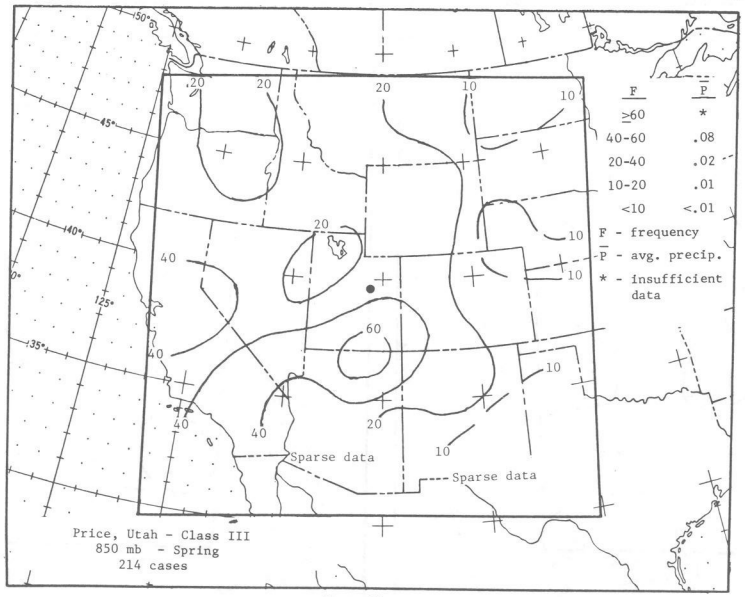



Chart 26 - IIIa

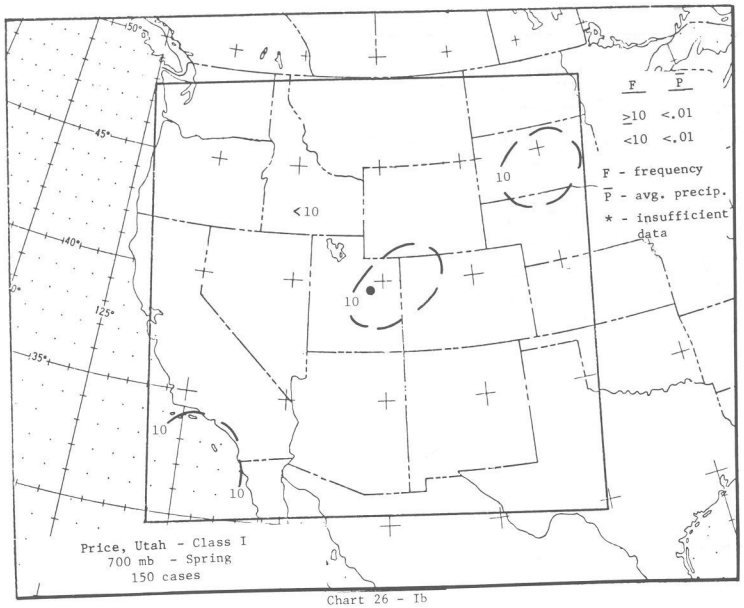



Chart 26 - Ib

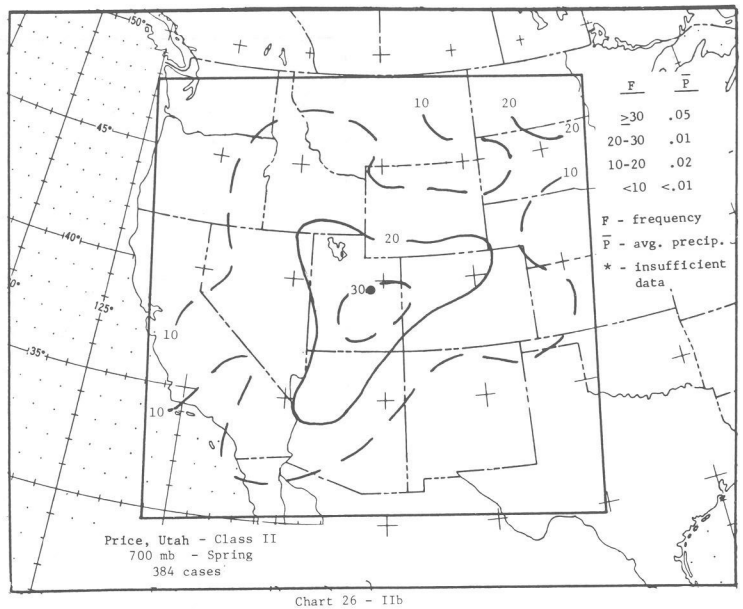



Chart 26 - IIb

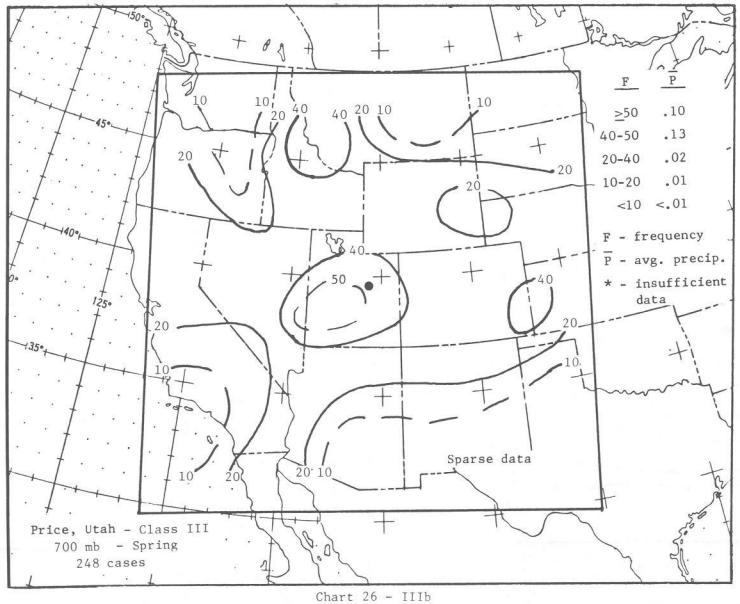



Chart 26 - IIIb

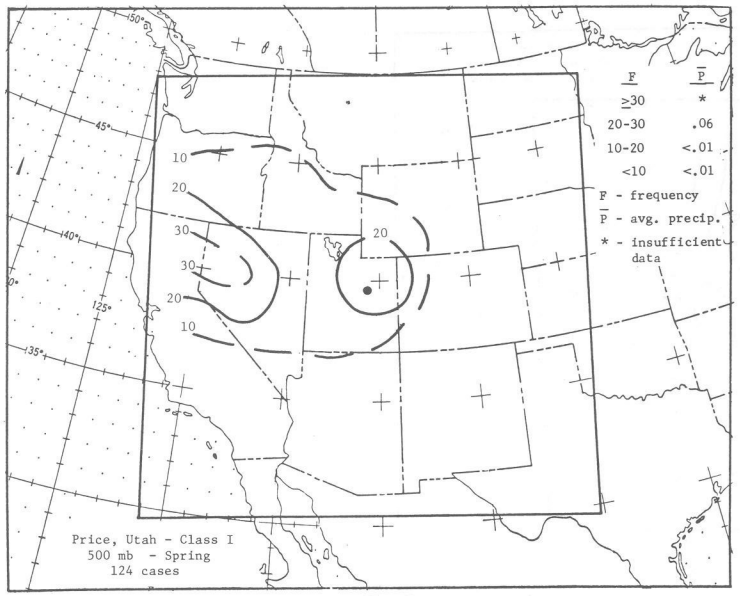



Chart 26 - Ic

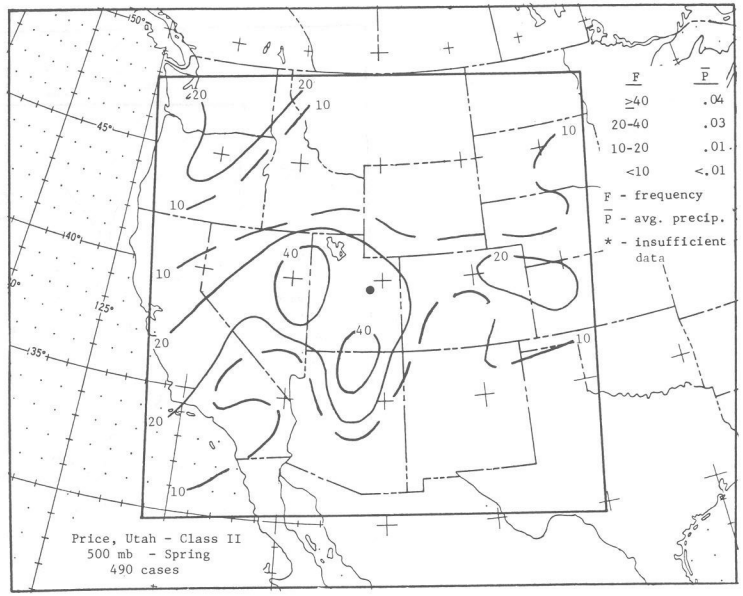



Chart 26 - IIc

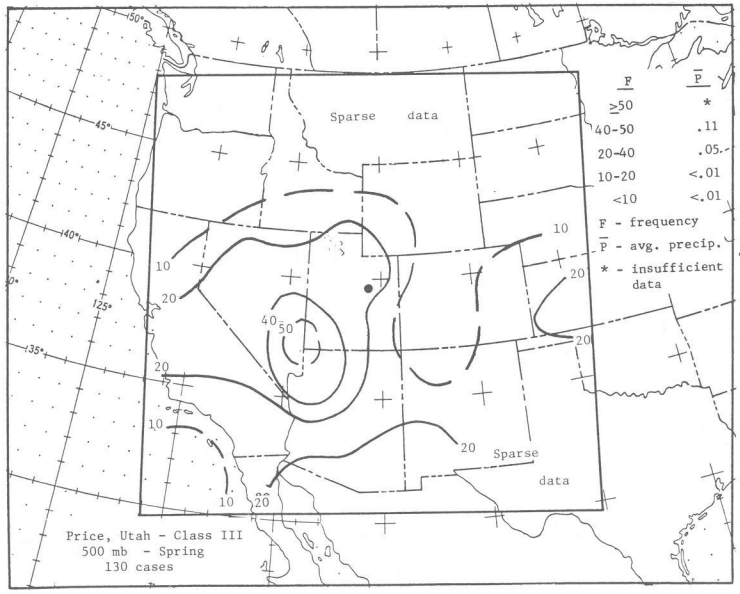



Chart 26 - IIIc

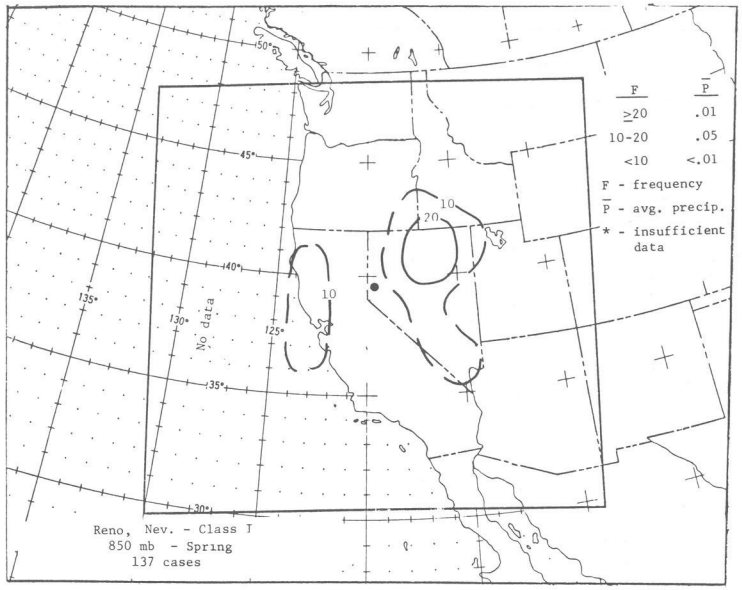



Chart 27 - Ia

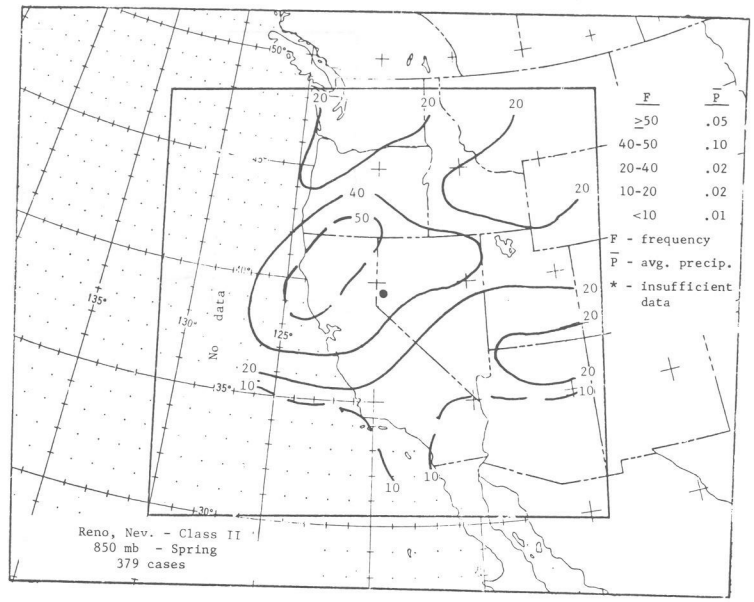



Chart 27 - IIa

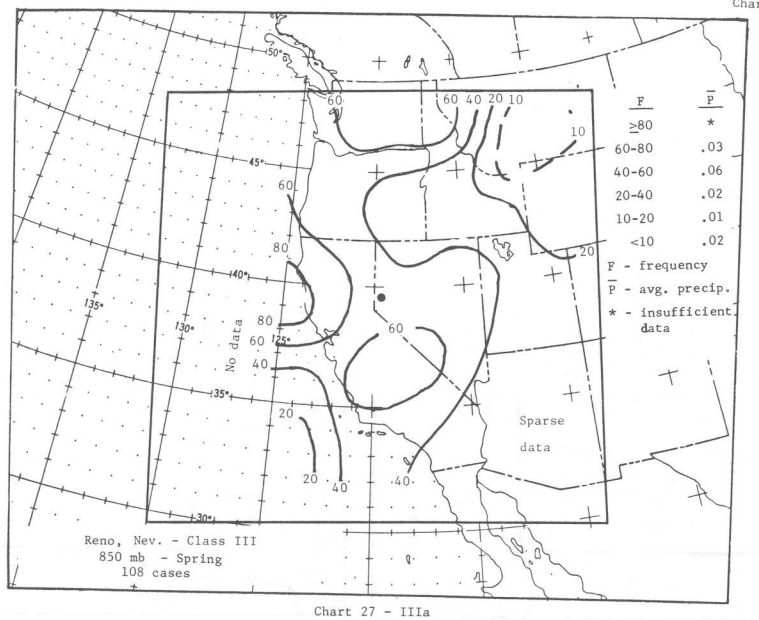



Chart 27 - IIIa

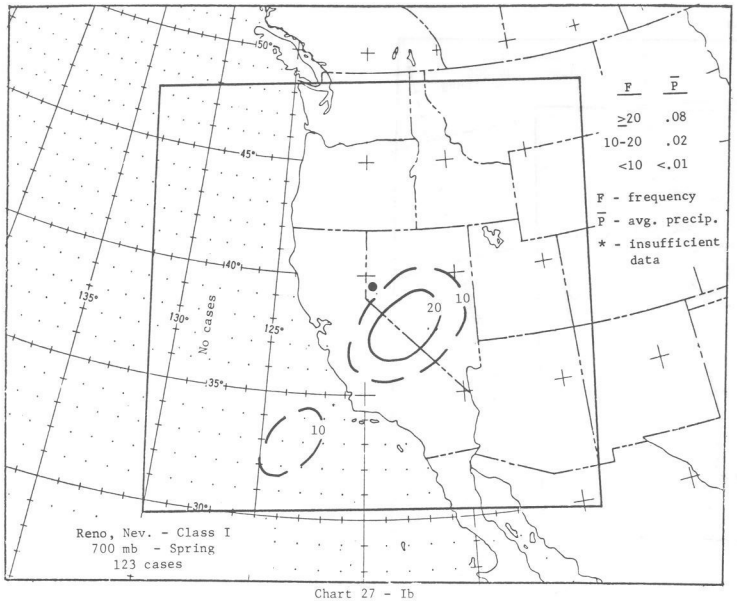



Chart 27 - Ib

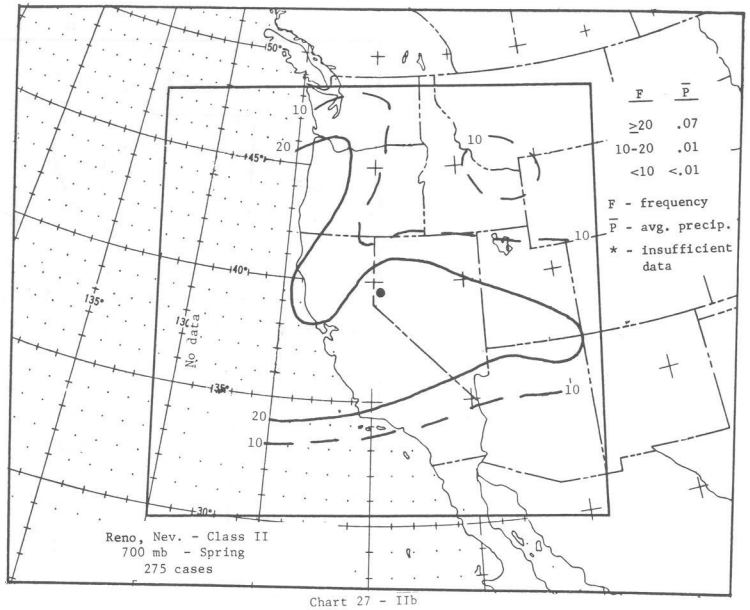



Chart 27 - IIb

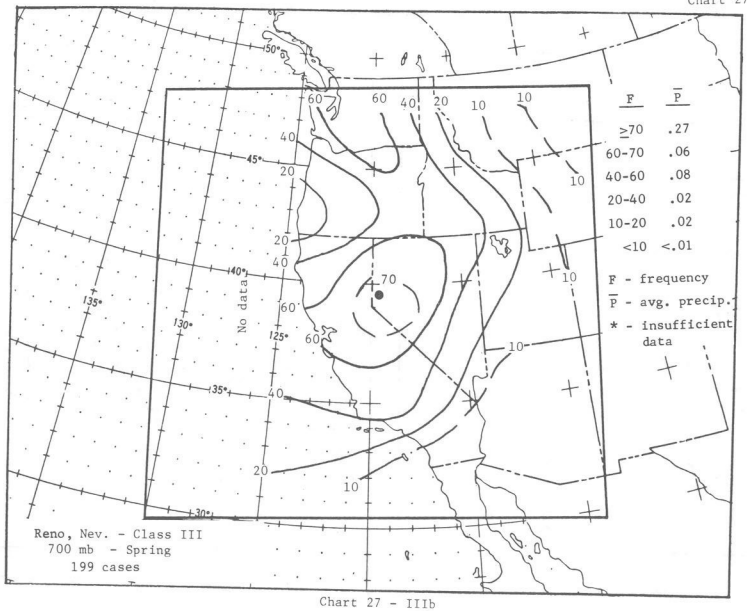



Chart 27 - IIIb

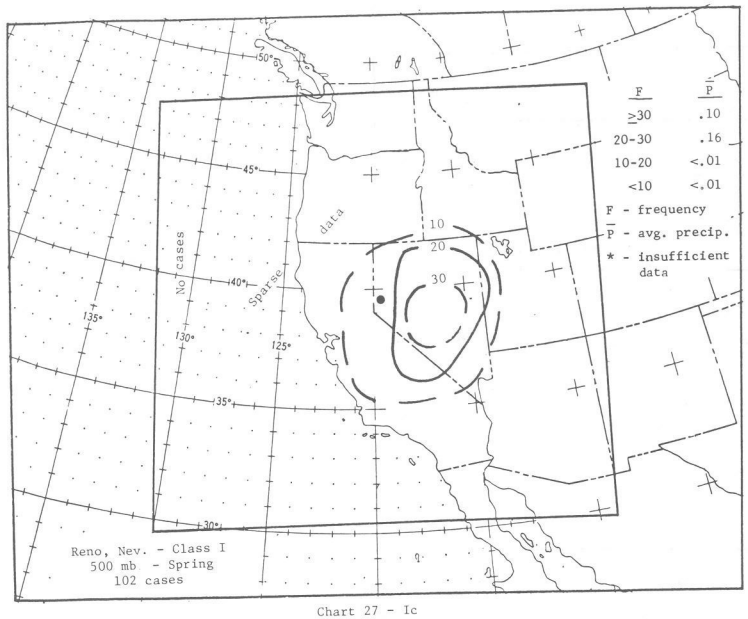



Chart 27 - Ic

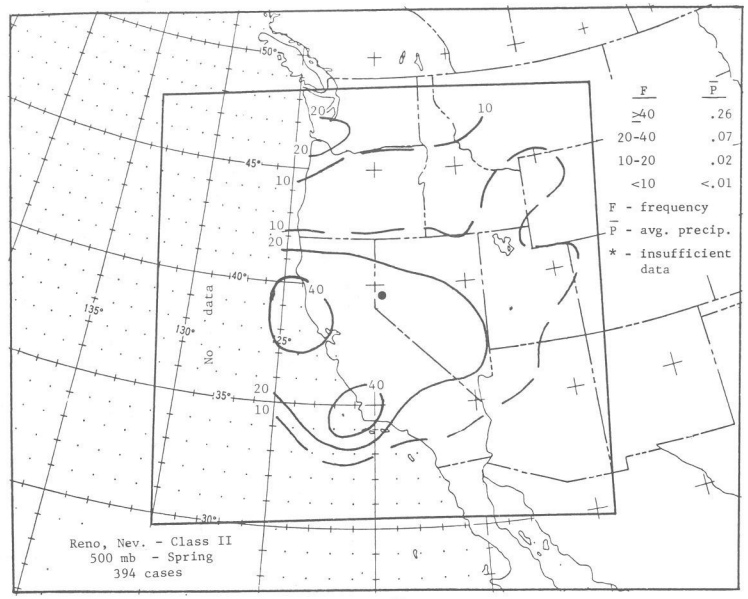



Chart 27 - IIc

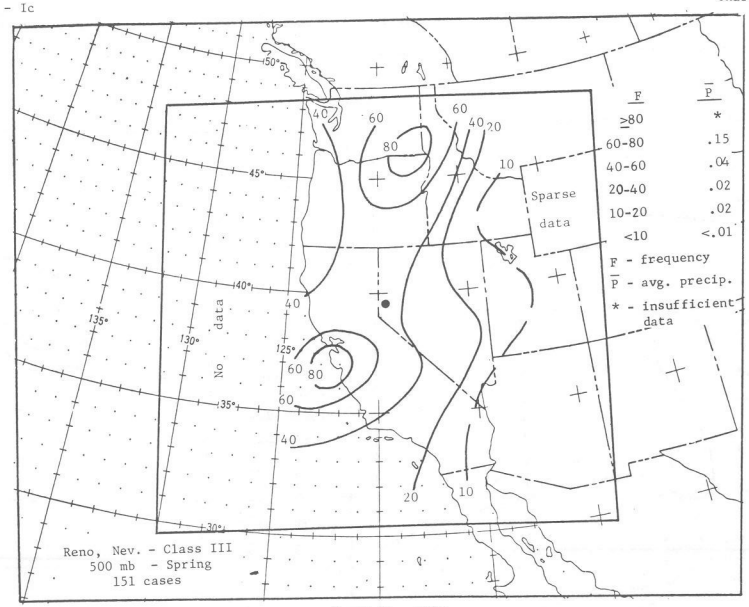



Chart 27 - IIIc

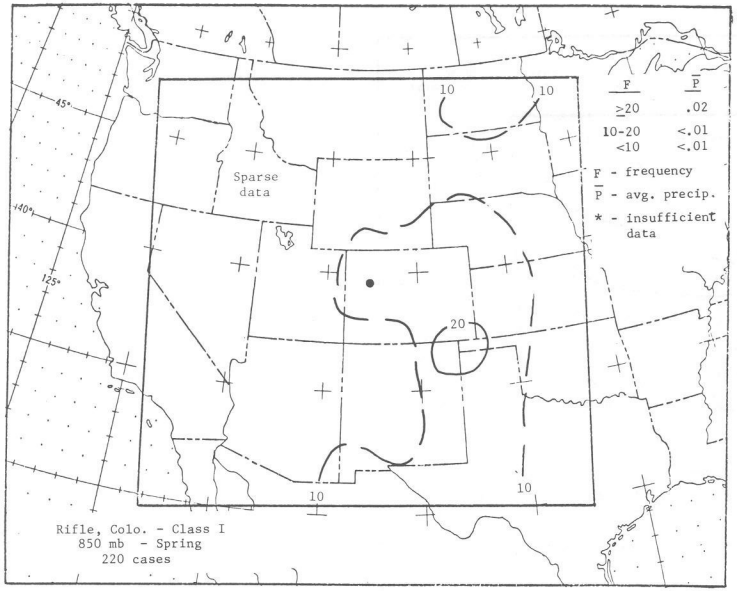



Chart 28 - Ia

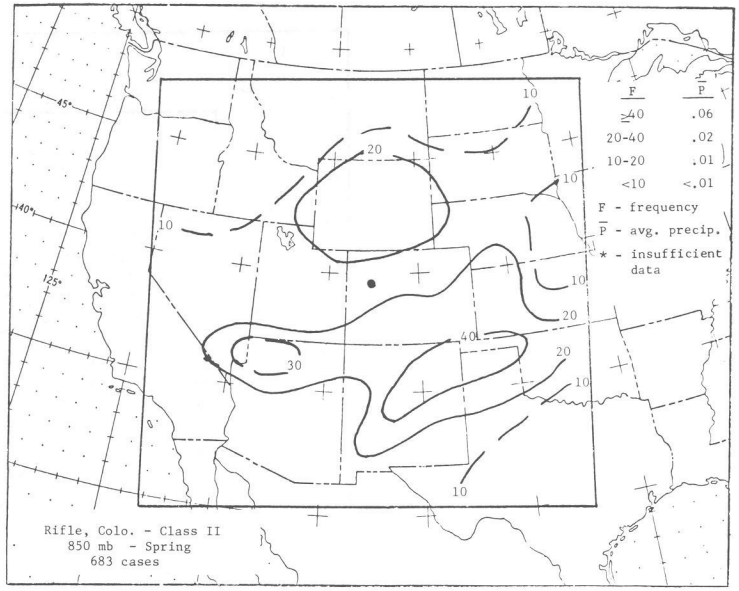



Chart 28 - IIa

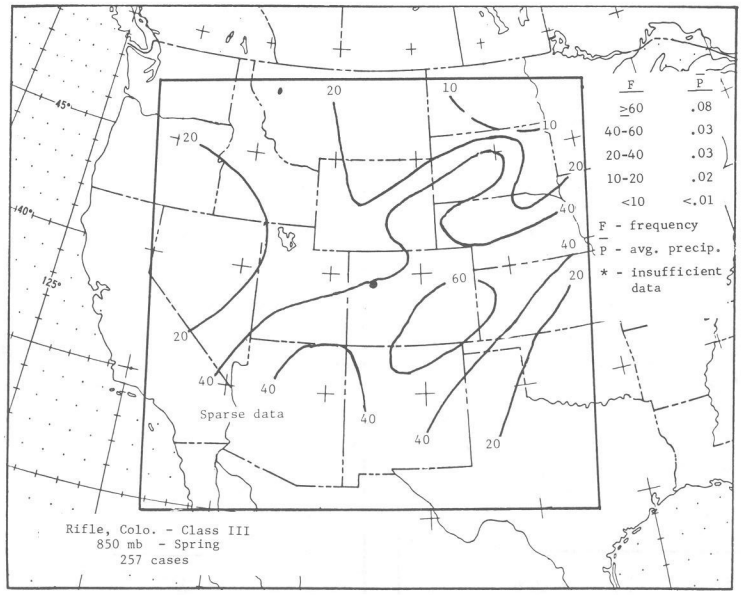



Chart 28 - IIIa

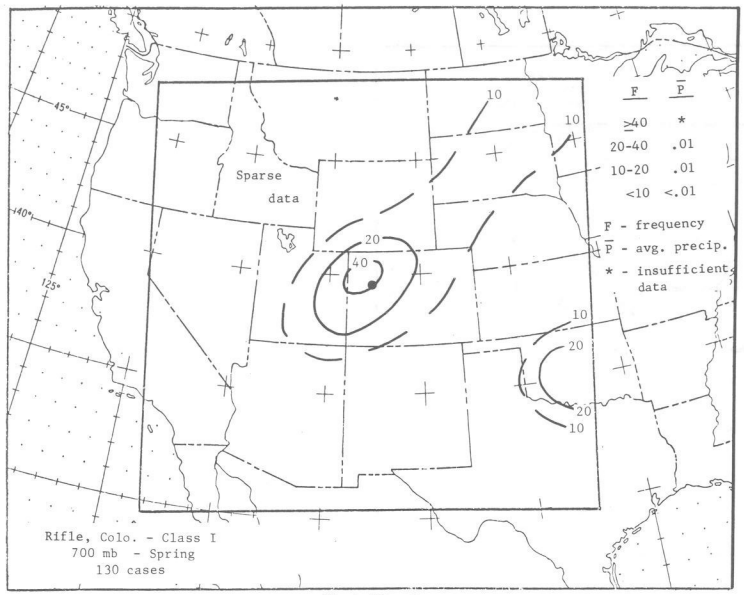



Chart 28 - Ib

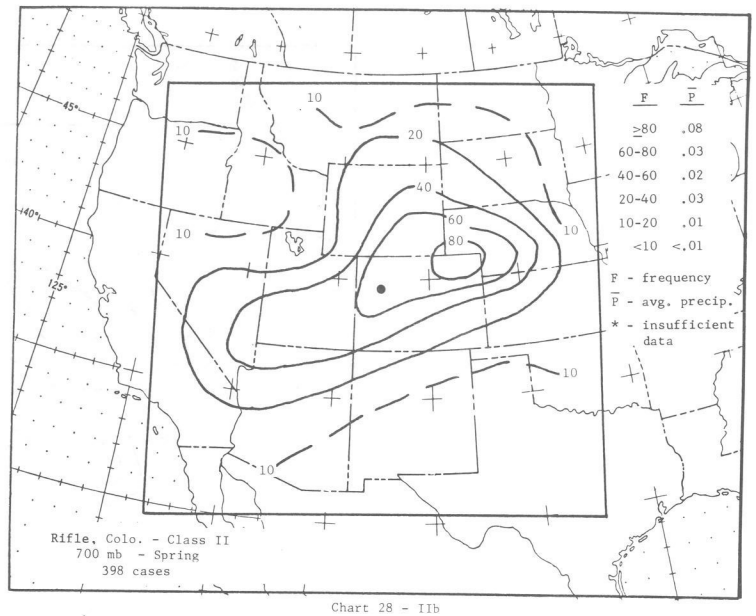



Chart 28 - IIb

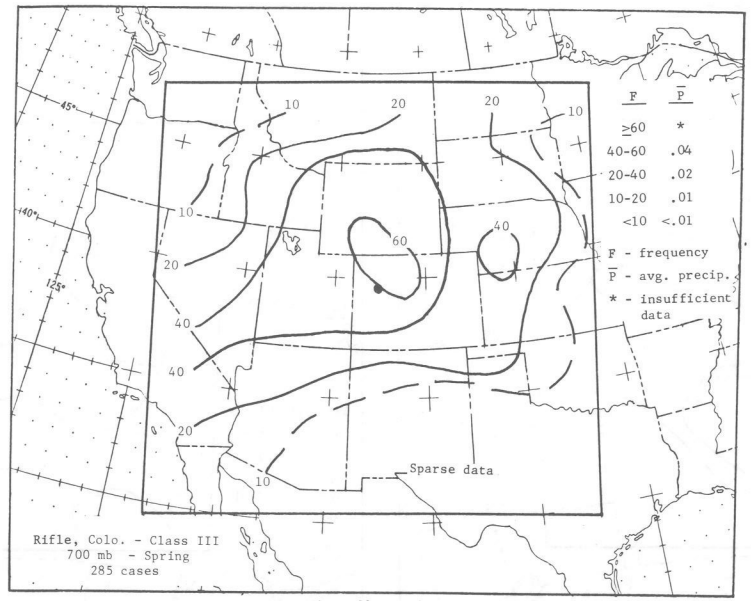



Chart 28 - IIIb

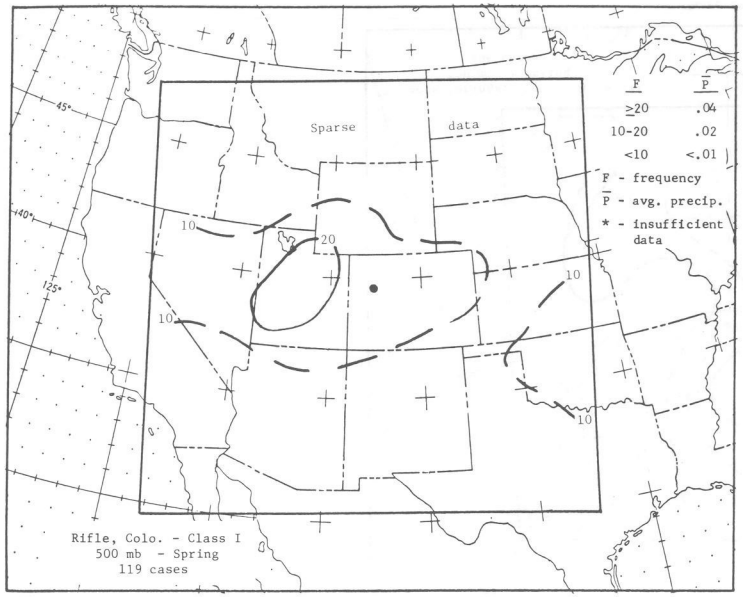



Chart 28 - Ic

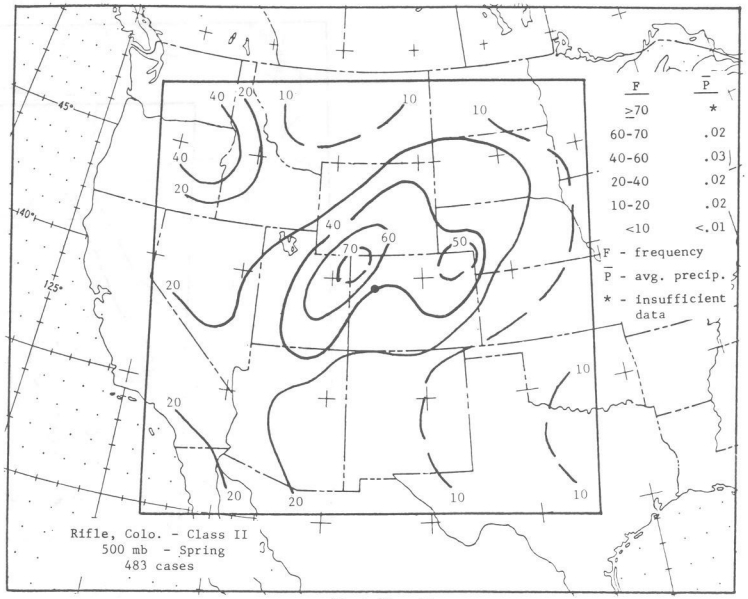



Chart 28 - IIc

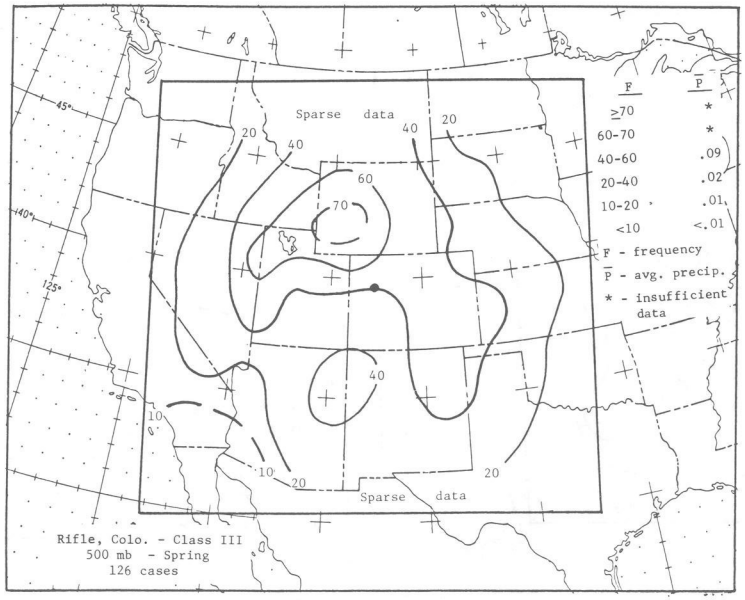



Chart 28 - IIIc

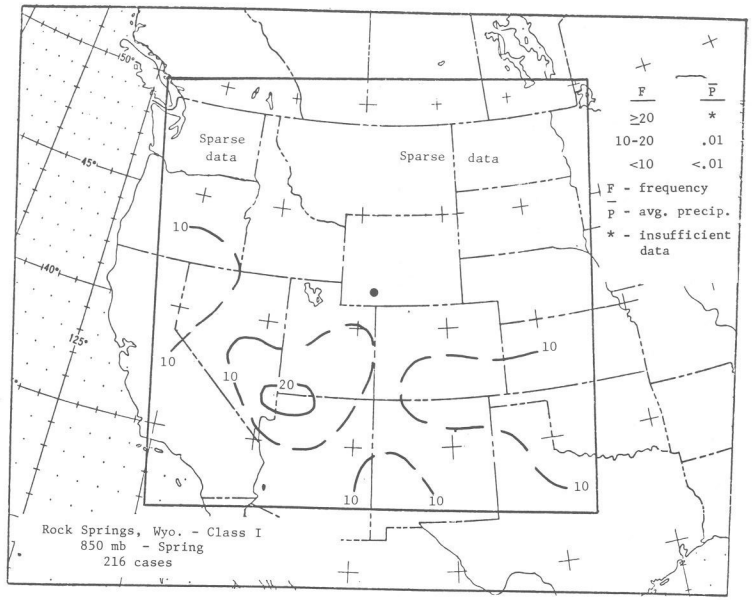



Chart 29 - Ia

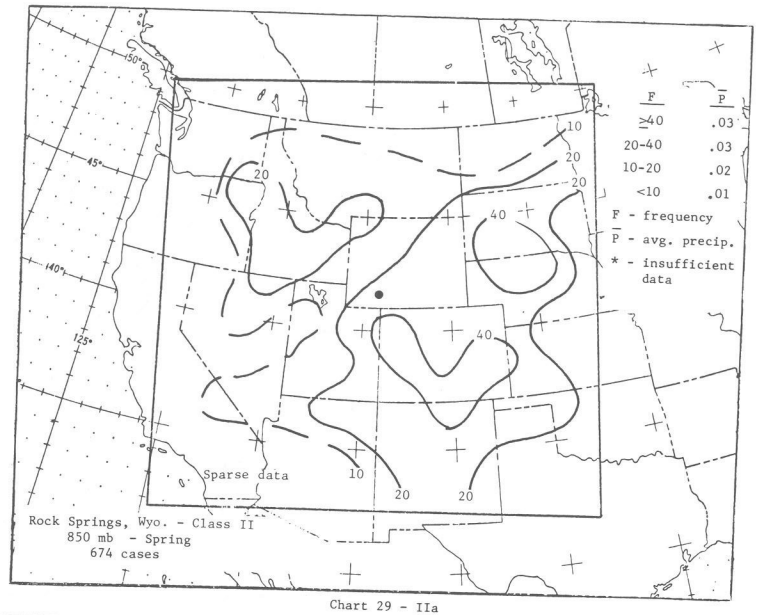



Chart 29 - IIa

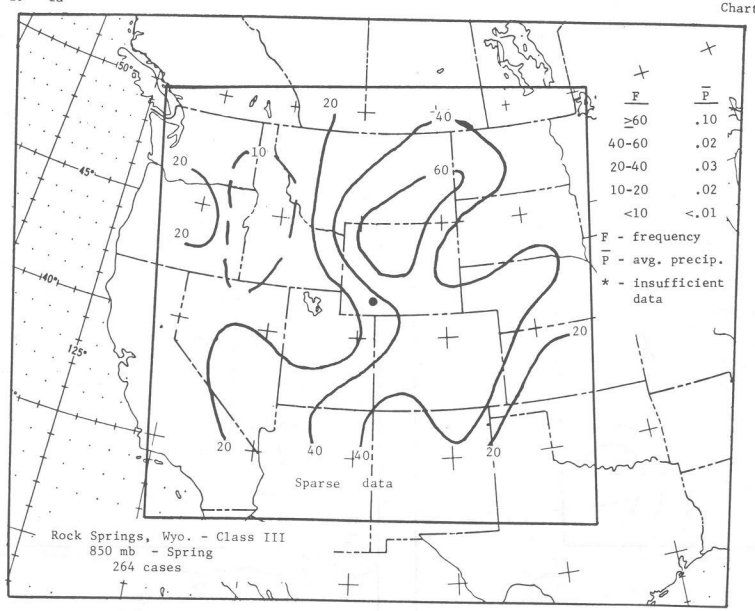



Chart 29 - IIIa

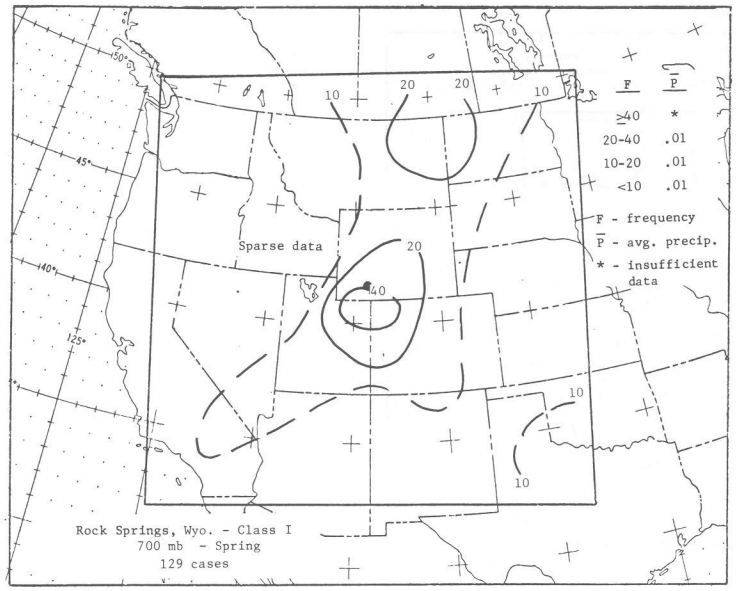



Chart 29 - Ib

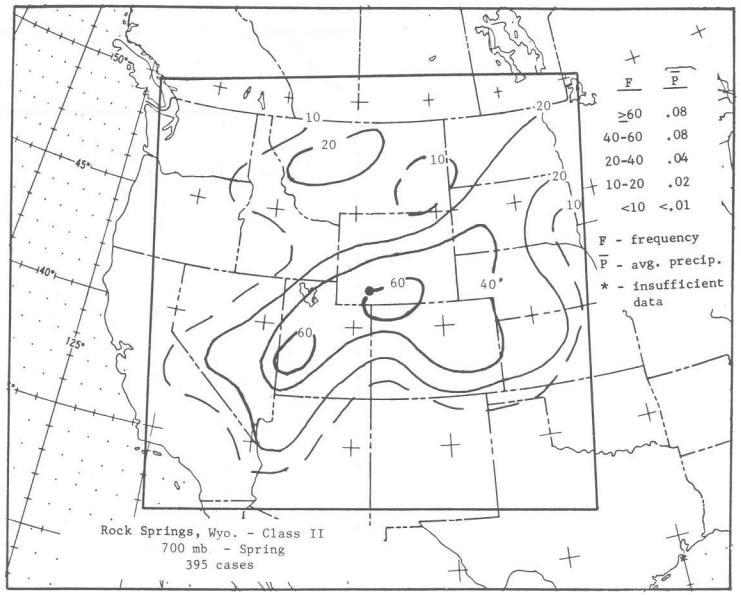



Chart 29 - IIb

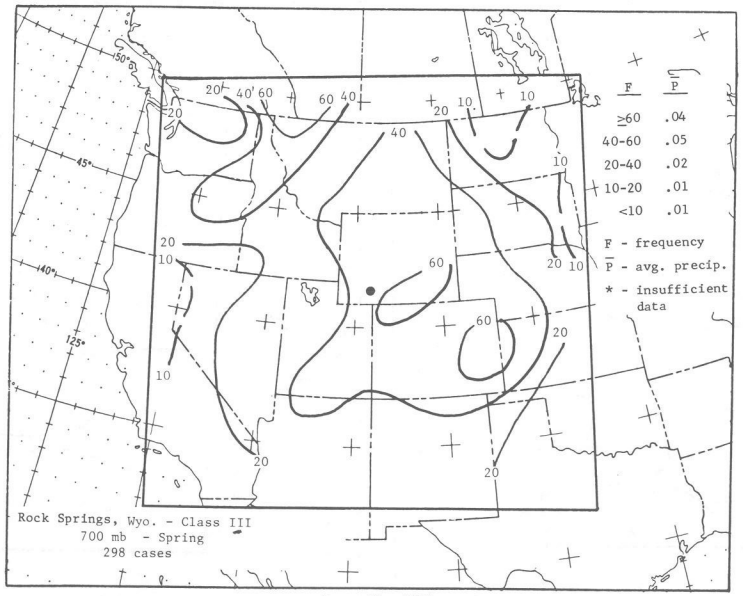



Chart 29 - IIIb

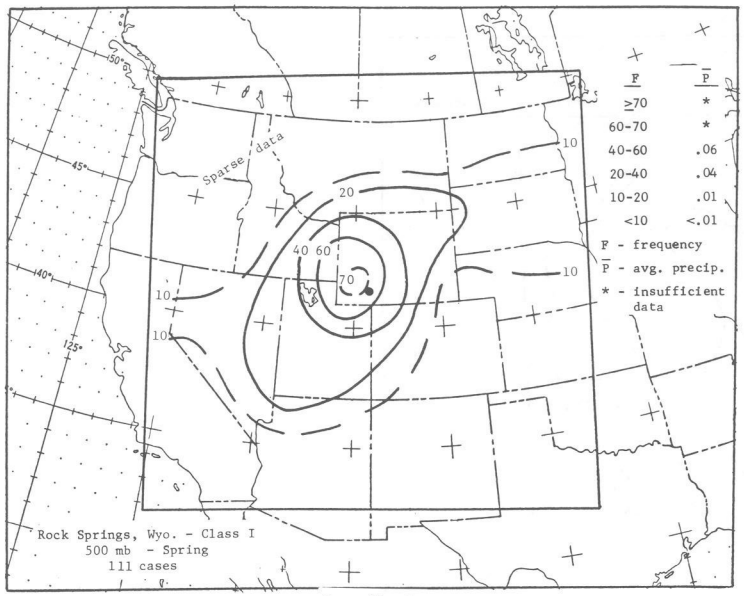



Chart 29 - Ic

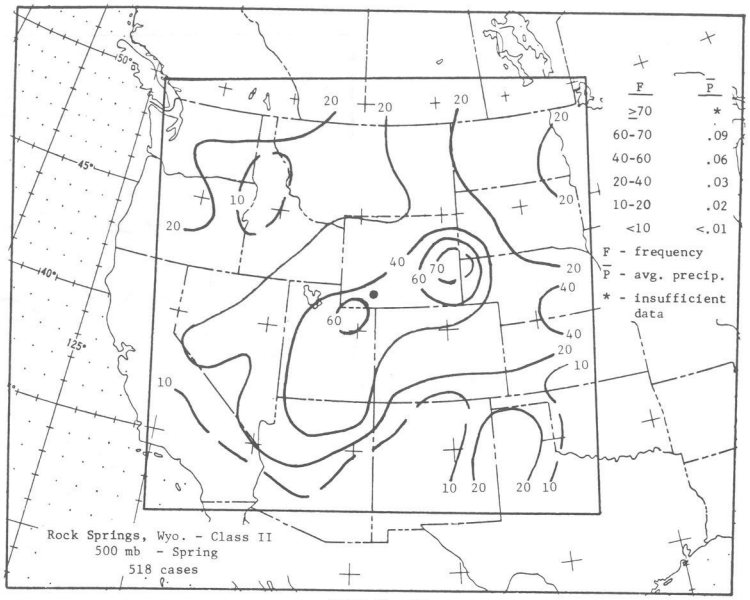



Chart 29 - IIc

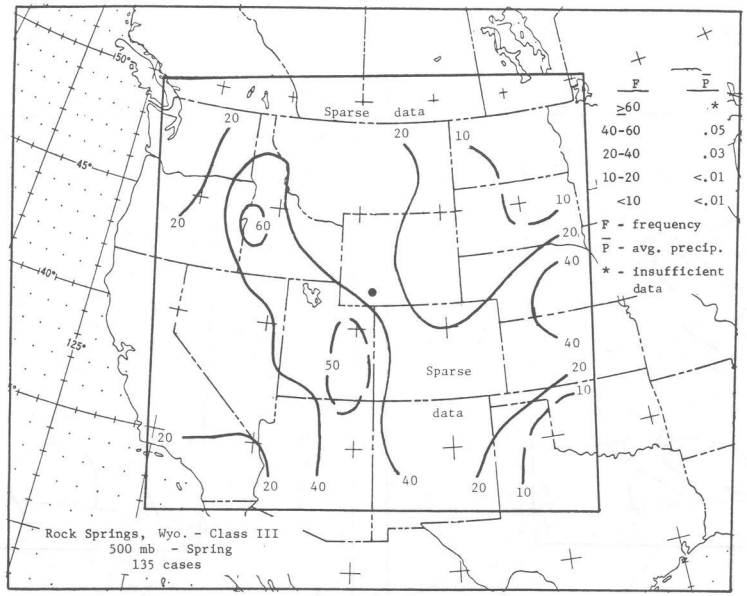



Chart 29 - IIIc

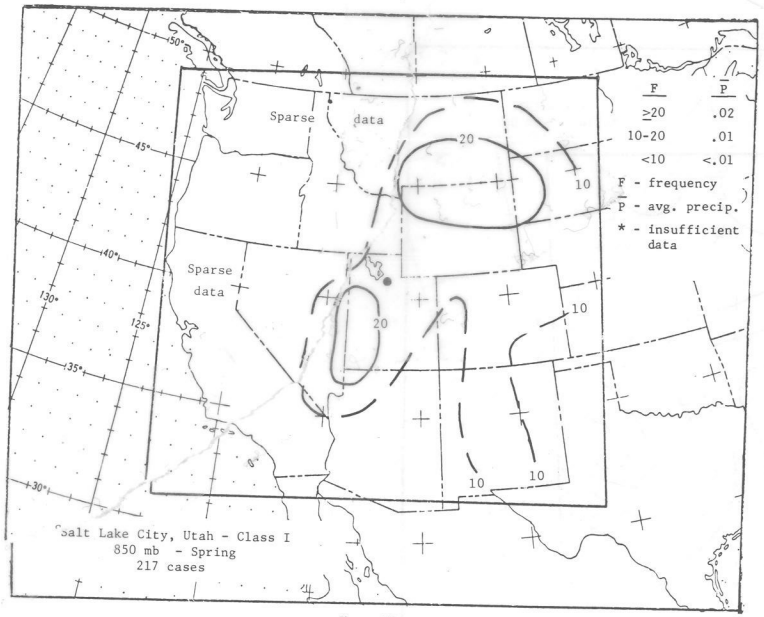



Chart 30 - Ia

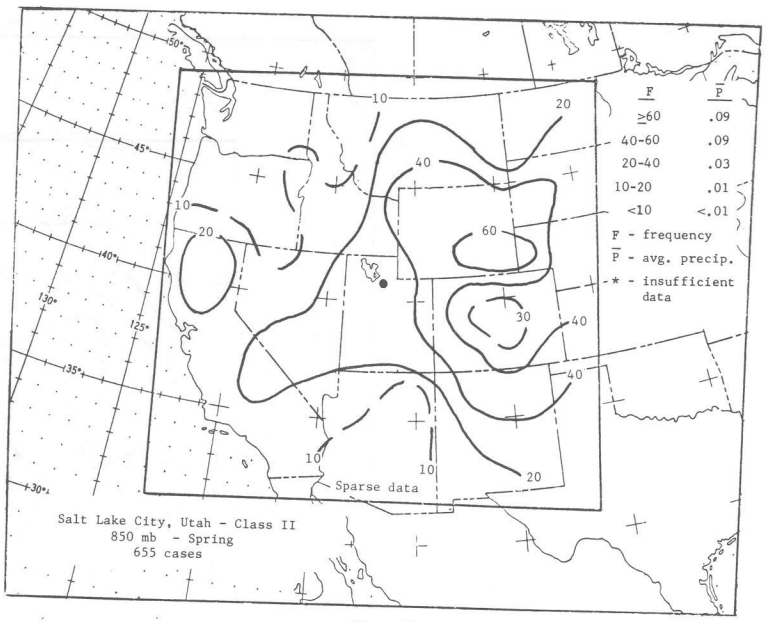



Chart 30 - IIa

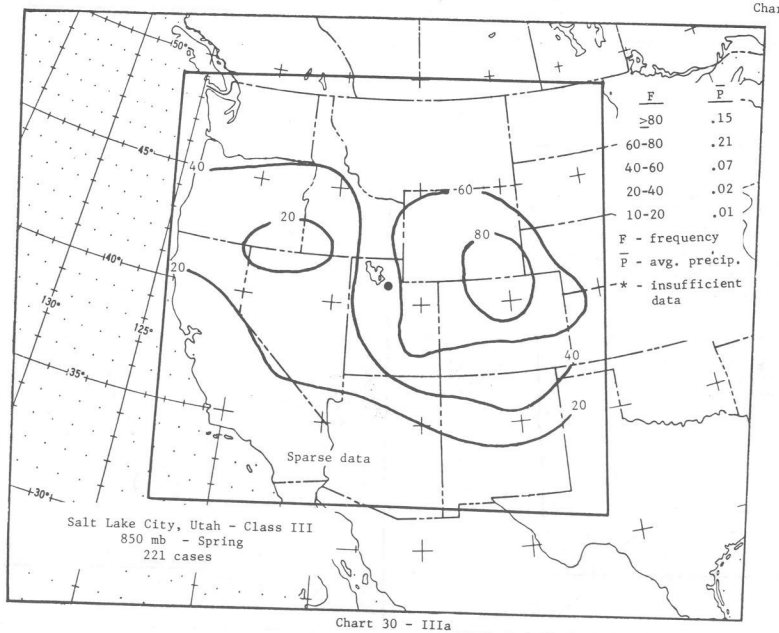



Chart 30 - IIIa

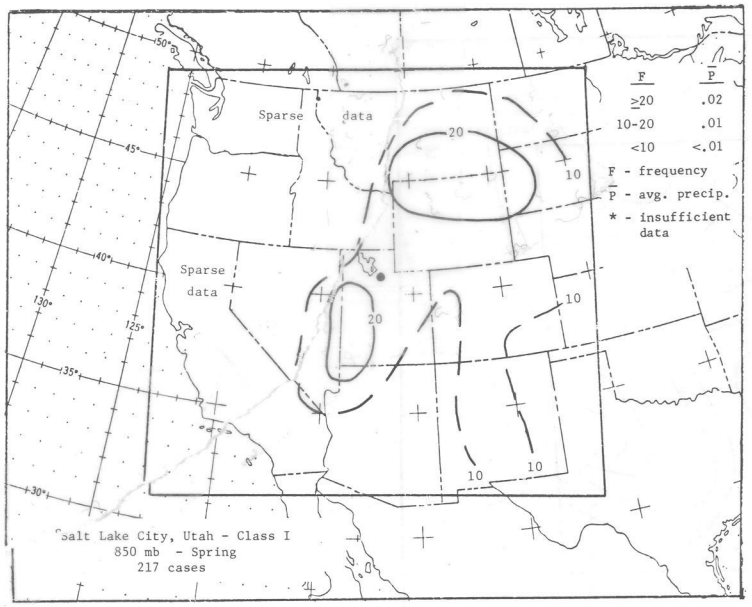



Chart 30 - Ia

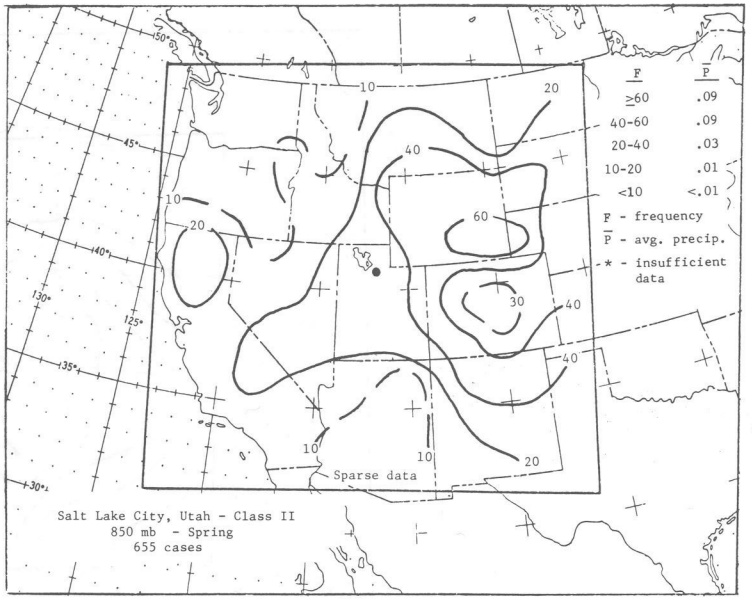



Chart 30 - IIa

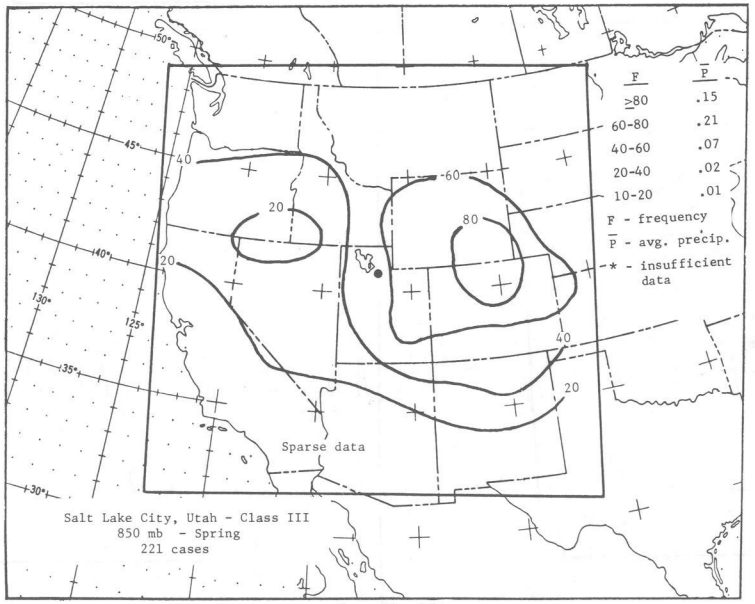



Chart 30 - IIIa

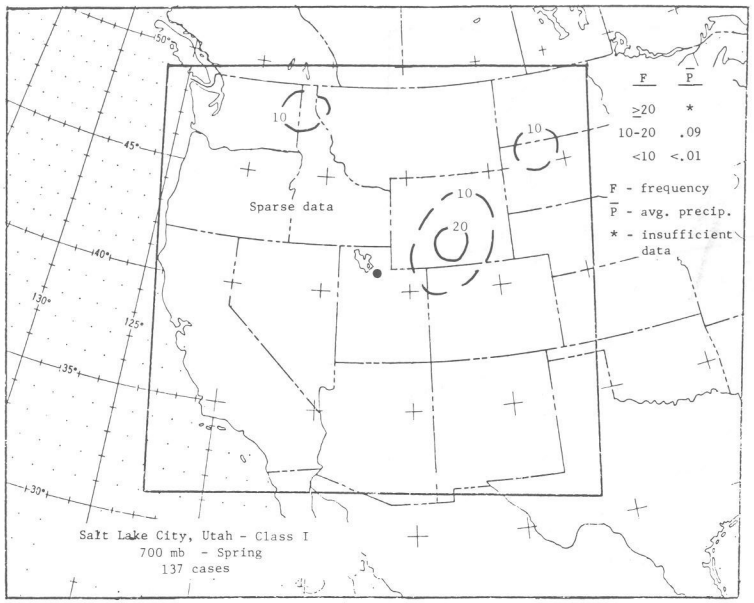



Chart 30 - Ib

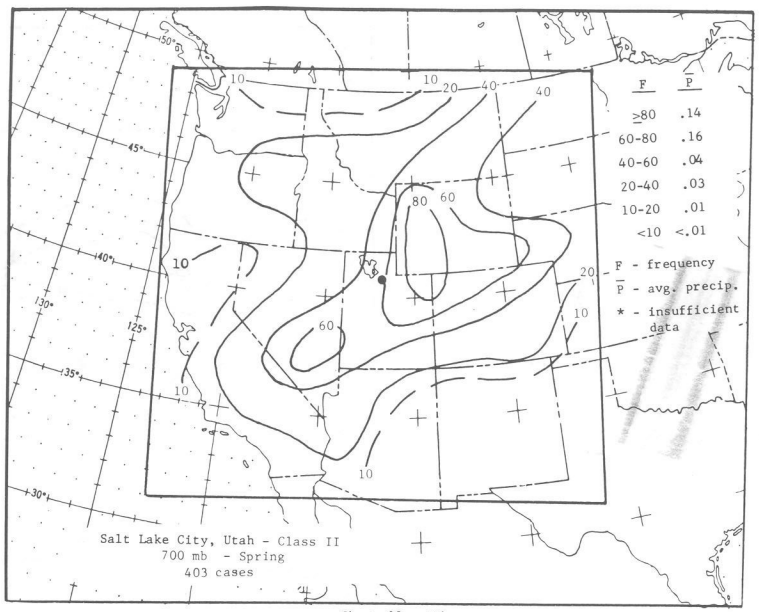



Chart 30 - IIb

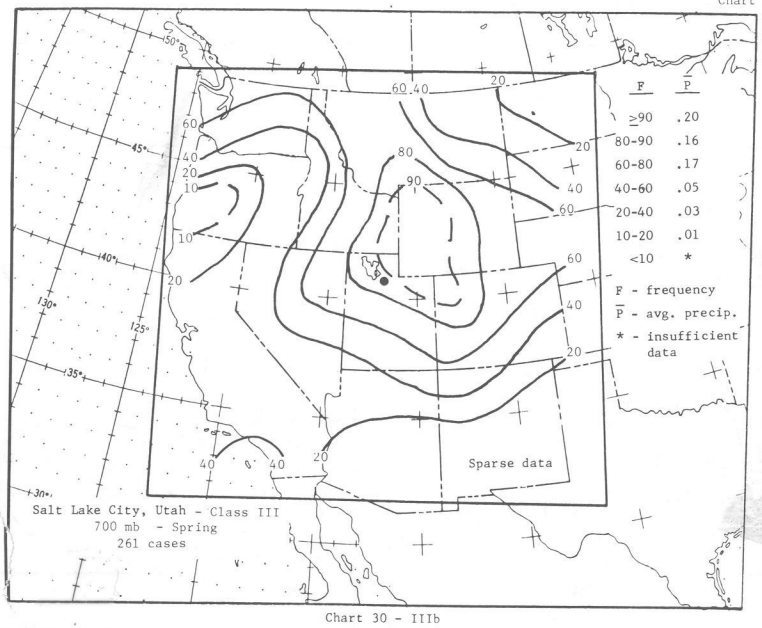



Chart 30 - IIIb

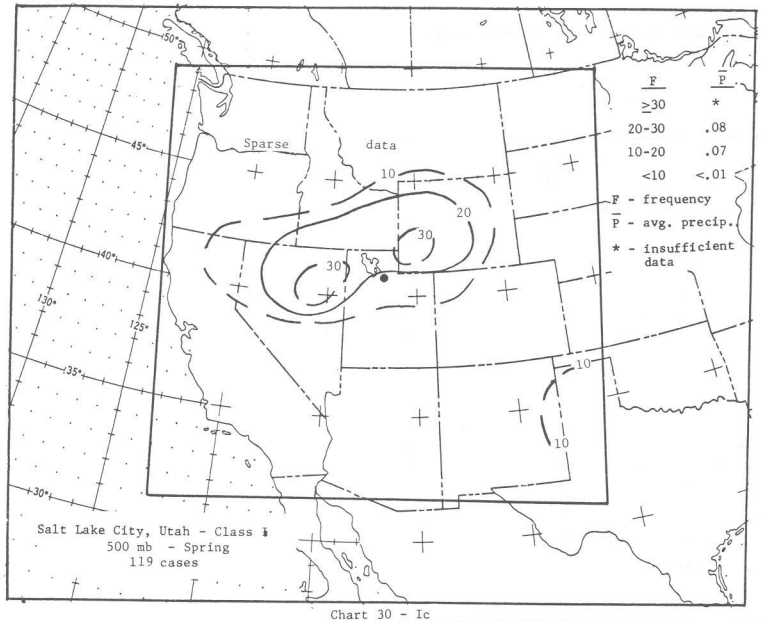



Chart 30 - Ic

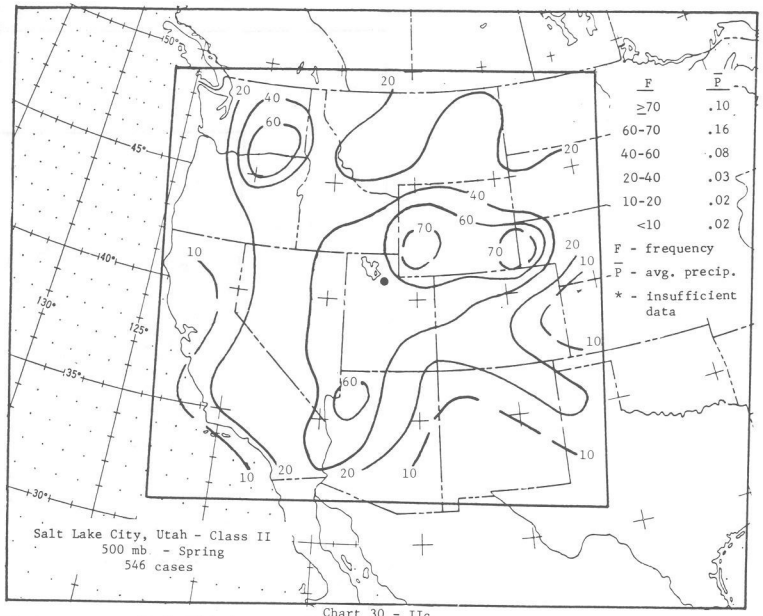



Chart 30 - IIc

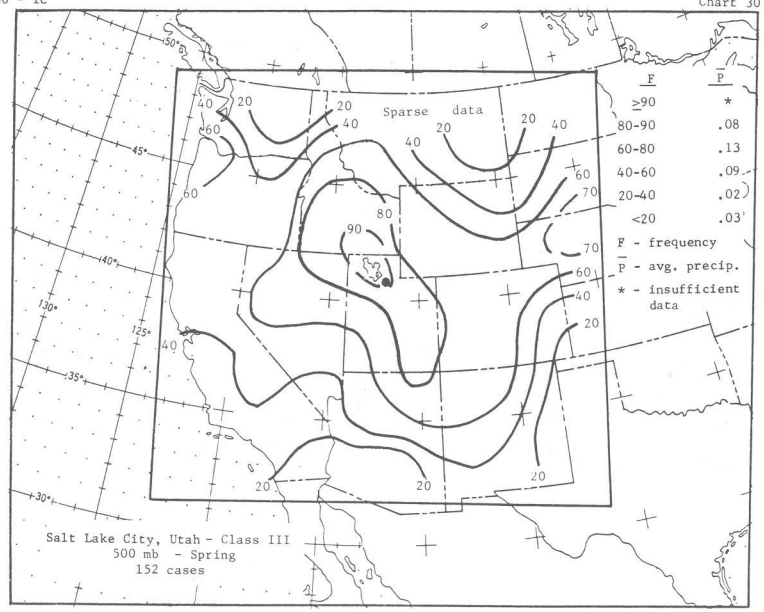



Chart 30 - IIIc

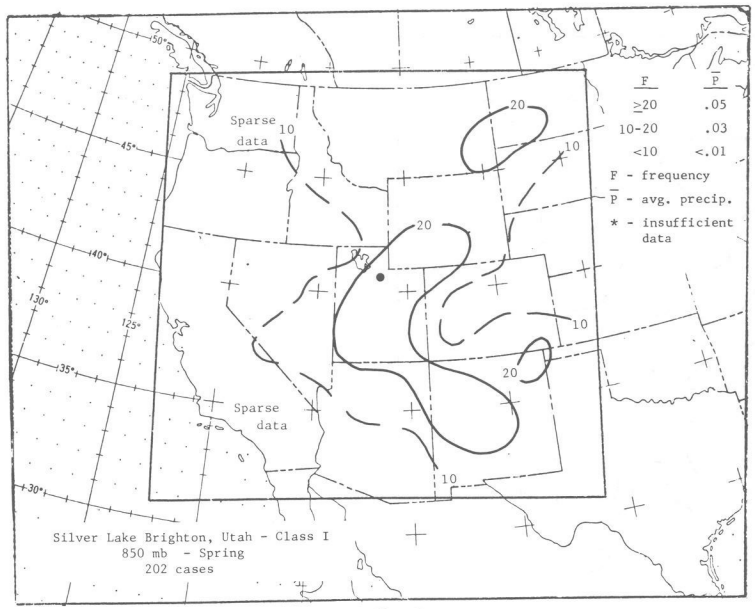



Chart 31 - Ia

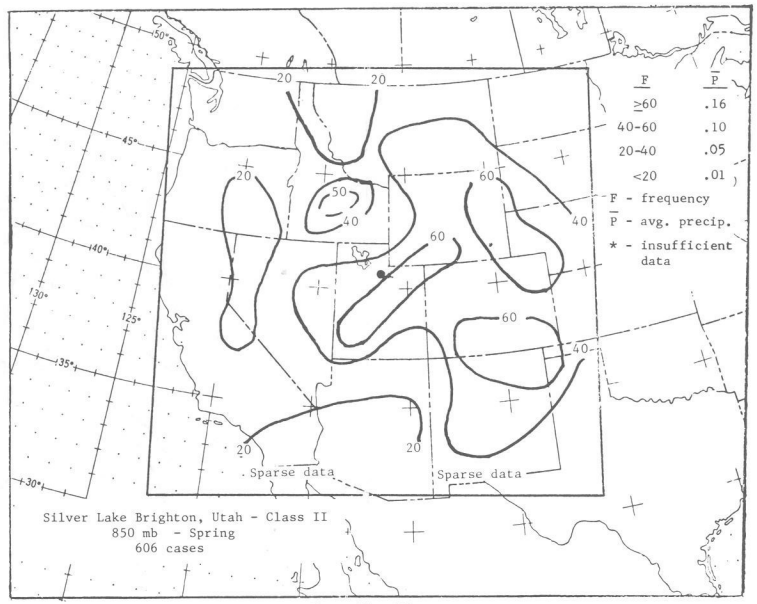



Chart 31 - IIa

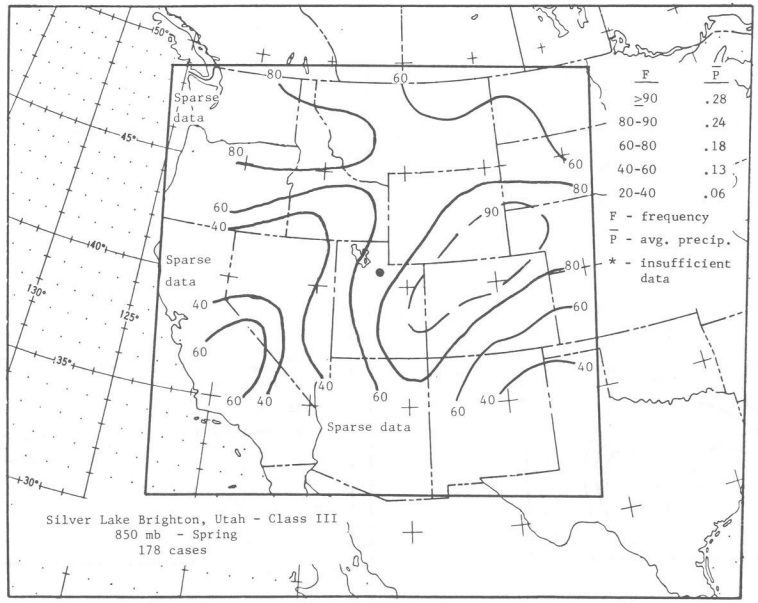



Chart 31 - IIIa

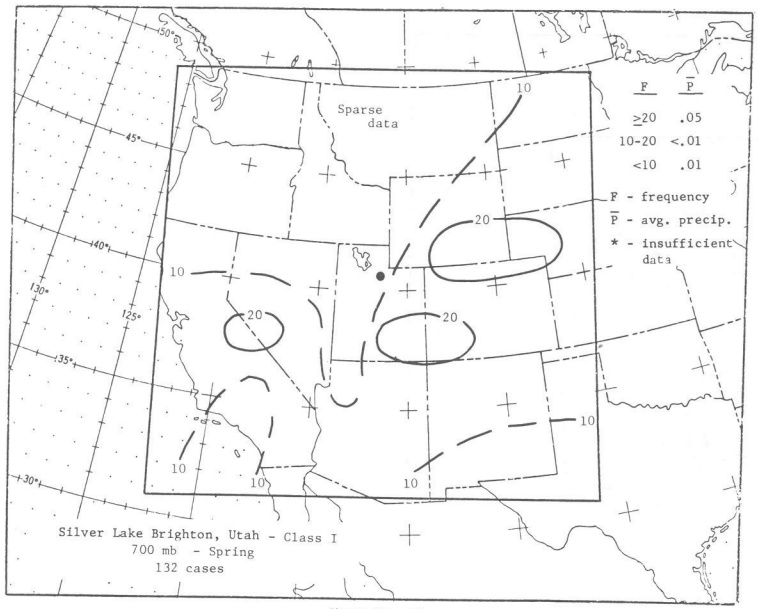



Chart 31 - Ib

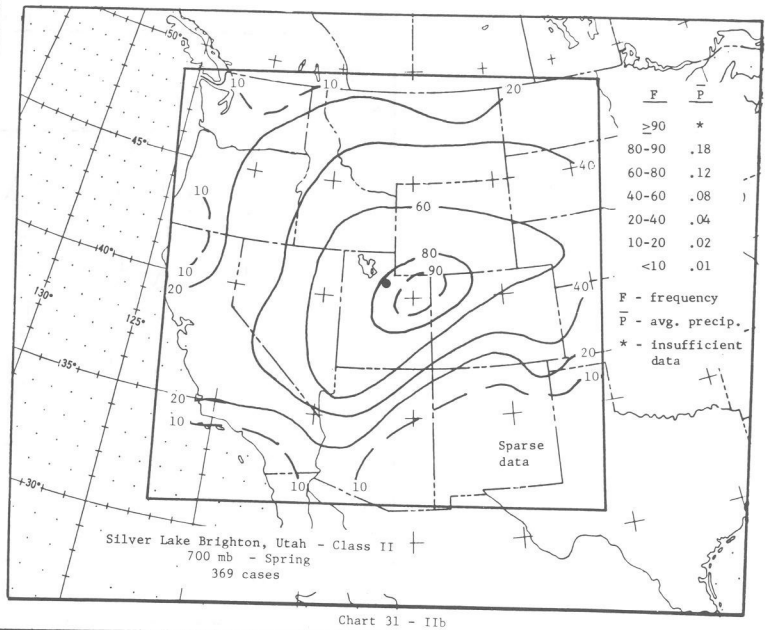



Chart 31 - IIb

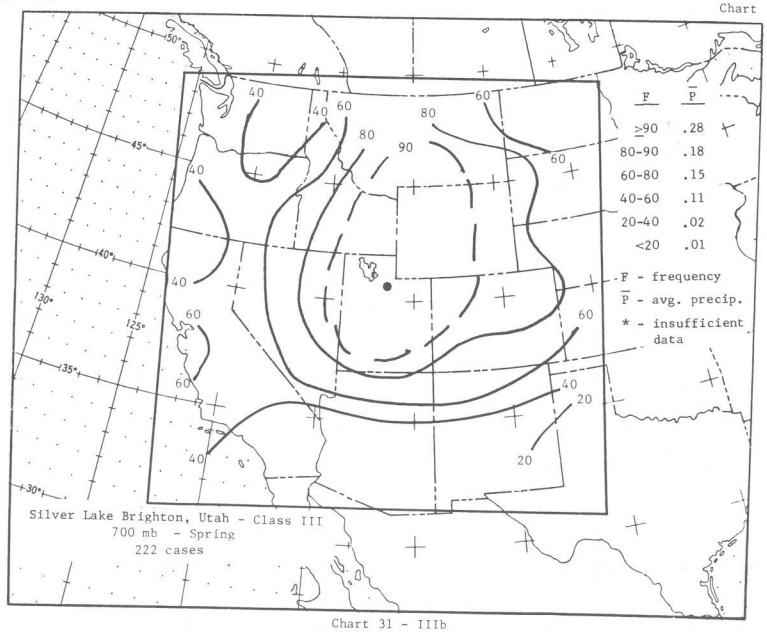



Chart 31 - IIIb

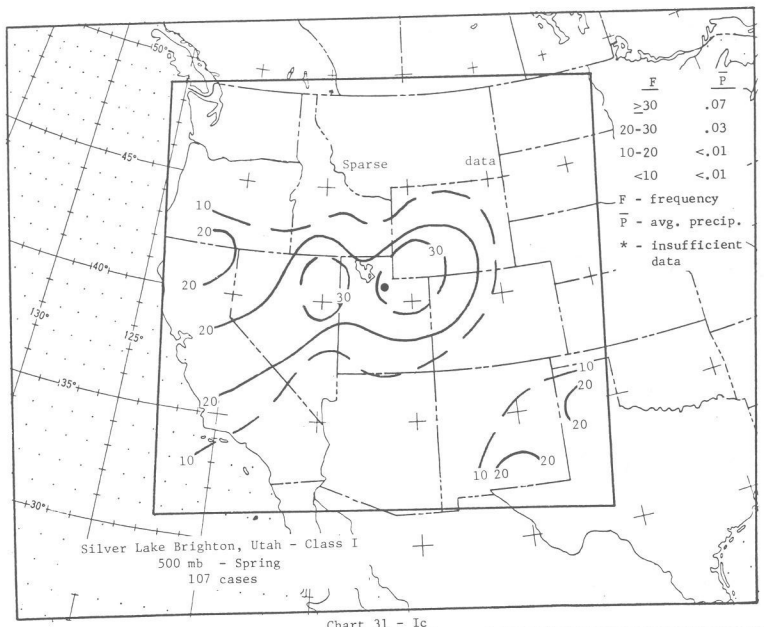



Chart 31 - Ic

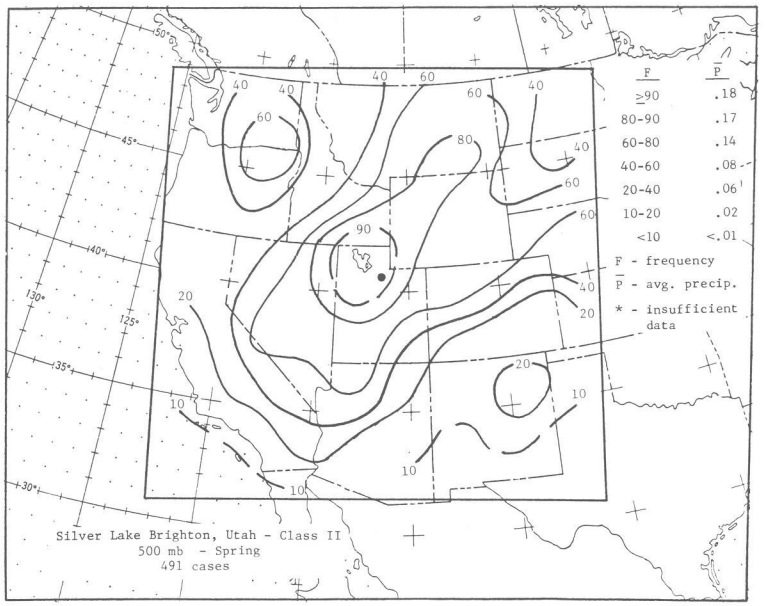



Chart 31 - IIc

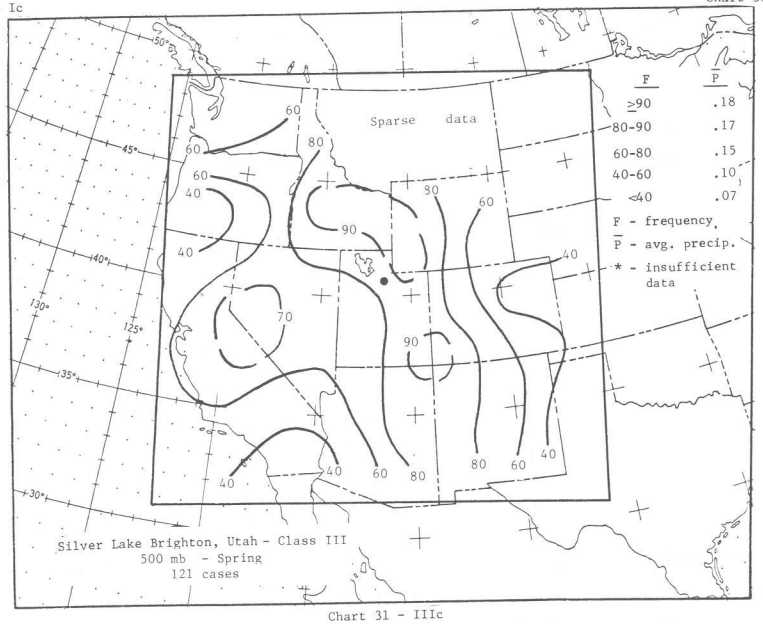



Chart 31 - IIIc

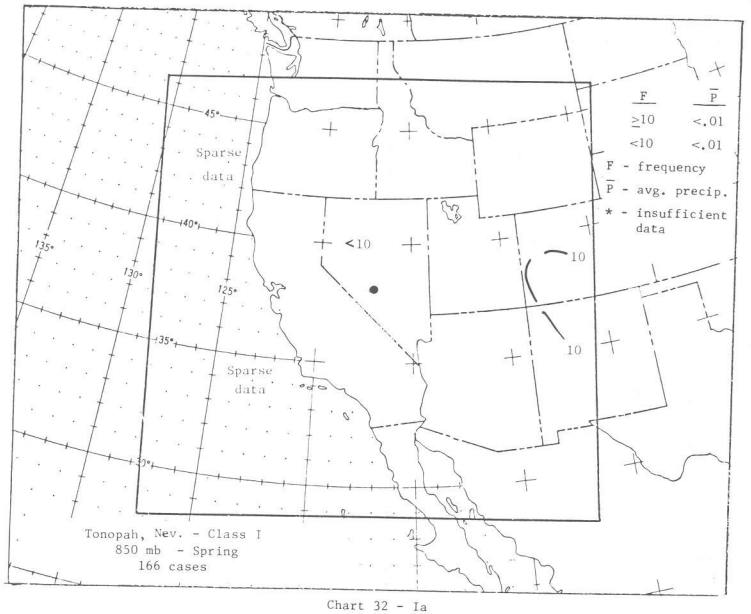



Chart 32 - Ia

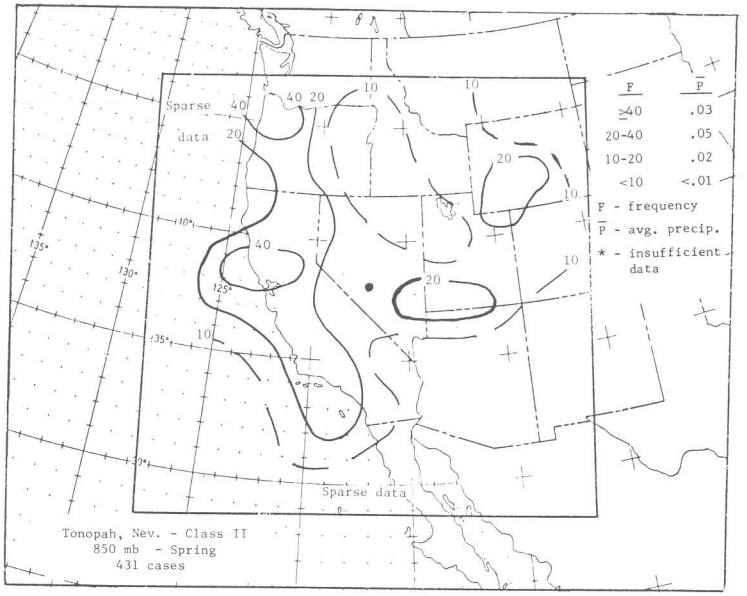



Chart 32 - IIa

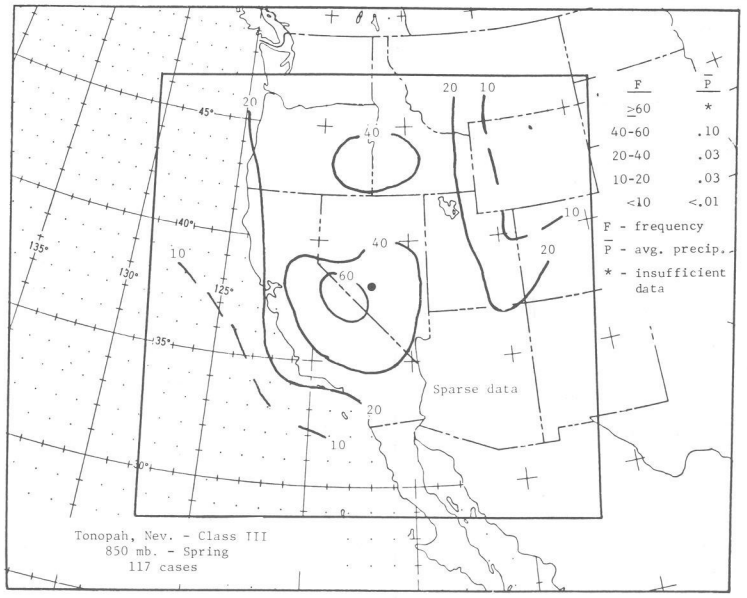



Chart 32 - IIIa

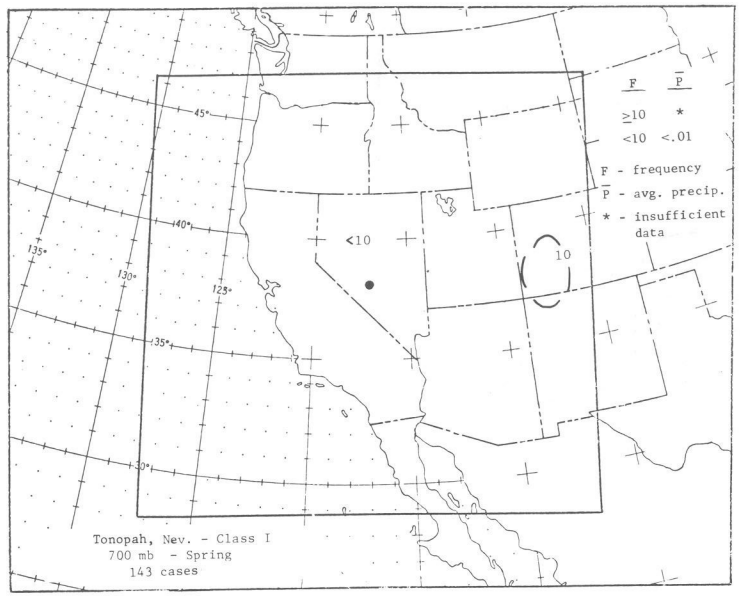



Chart 32 - Ib

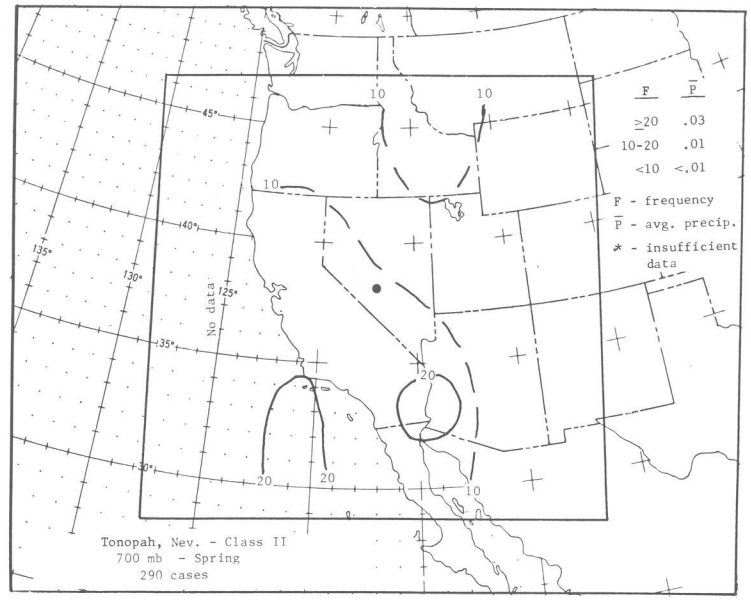



Chart 32 - IIb

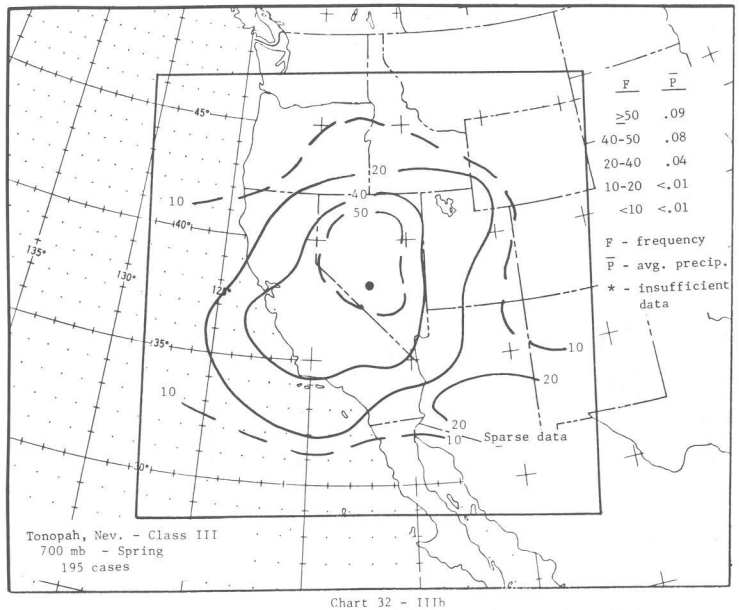



Chart 32 - IIIb

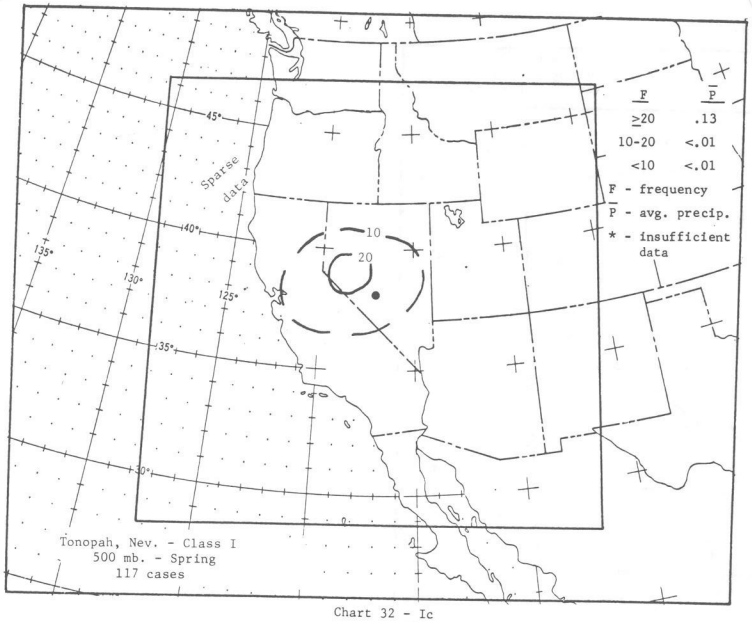



Chart 32 - Ic

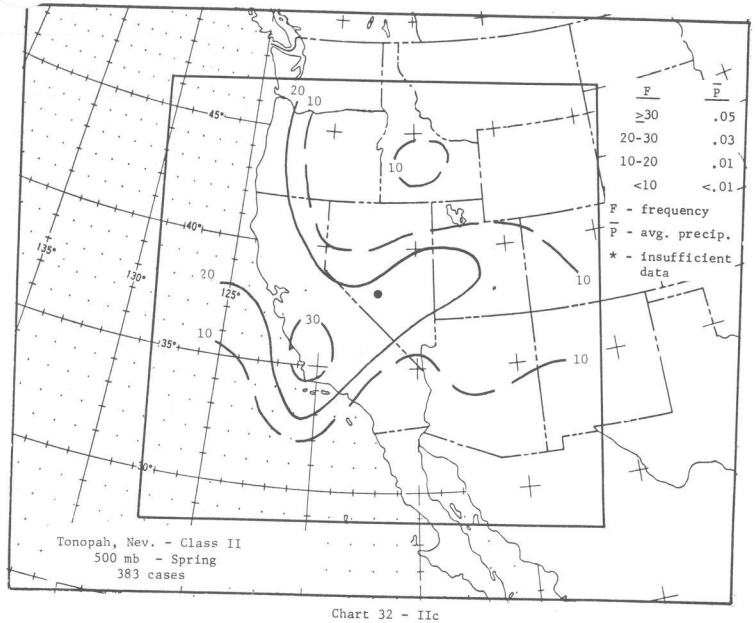



Chart 32 - IIc

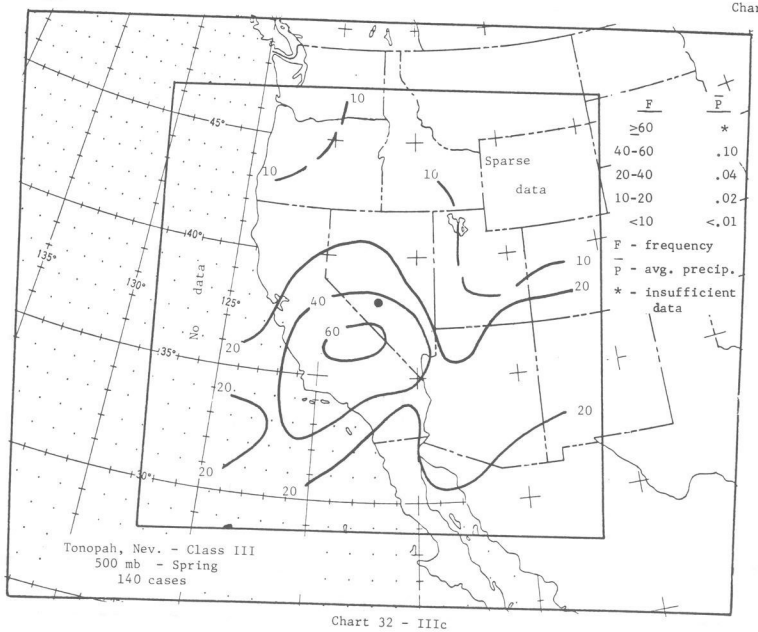



Chart 32 - IIIc

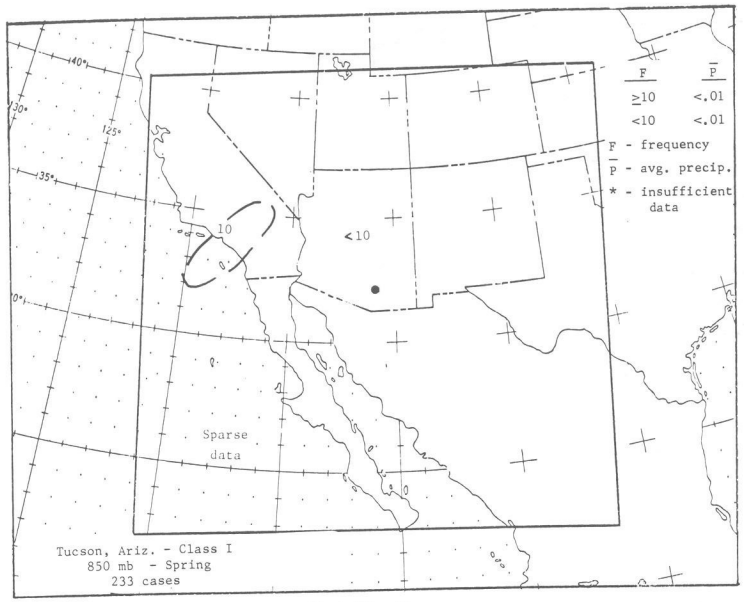



Chart 33 - Ia

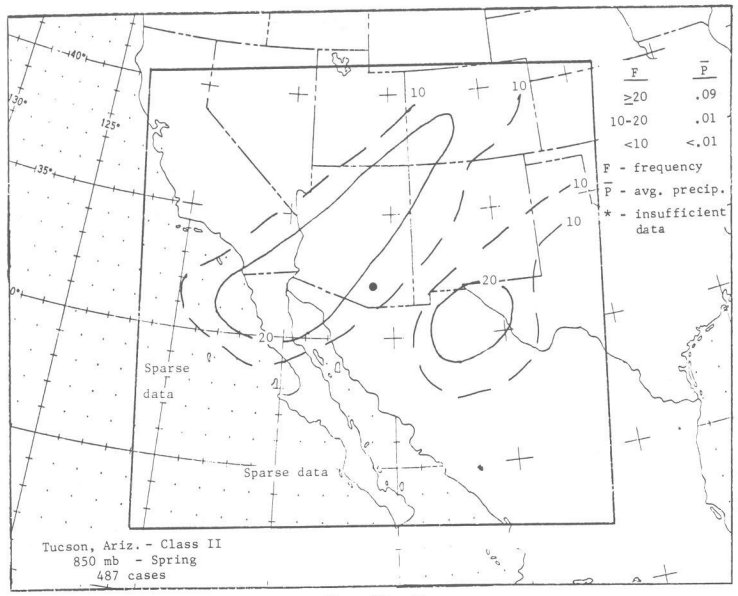



Chart 33 - IIa

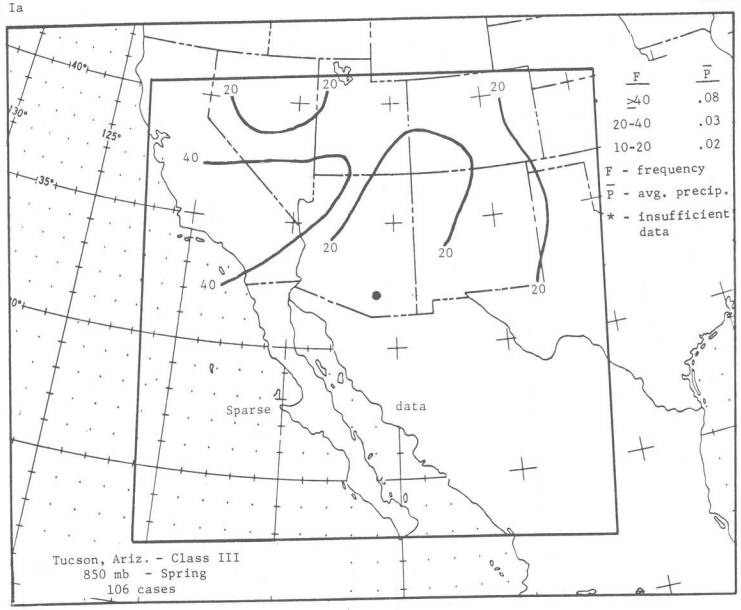



Chart 33 - IIIa

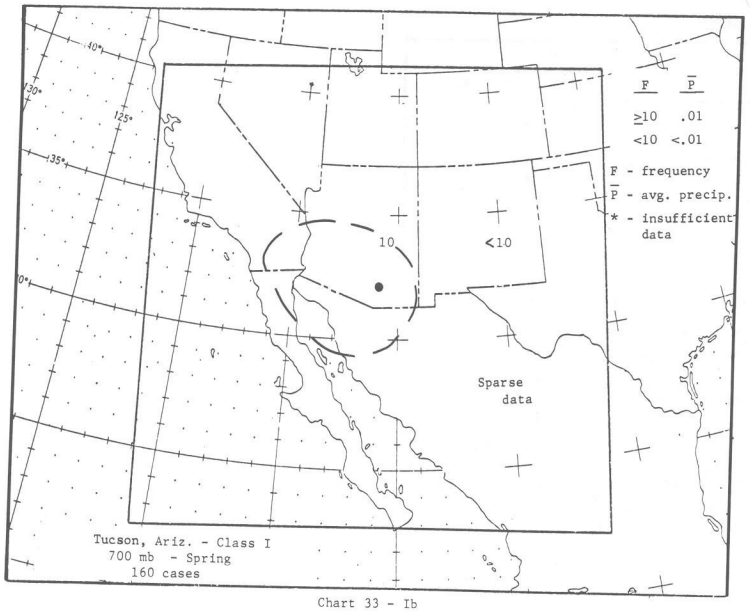



Chart 33 - Ib

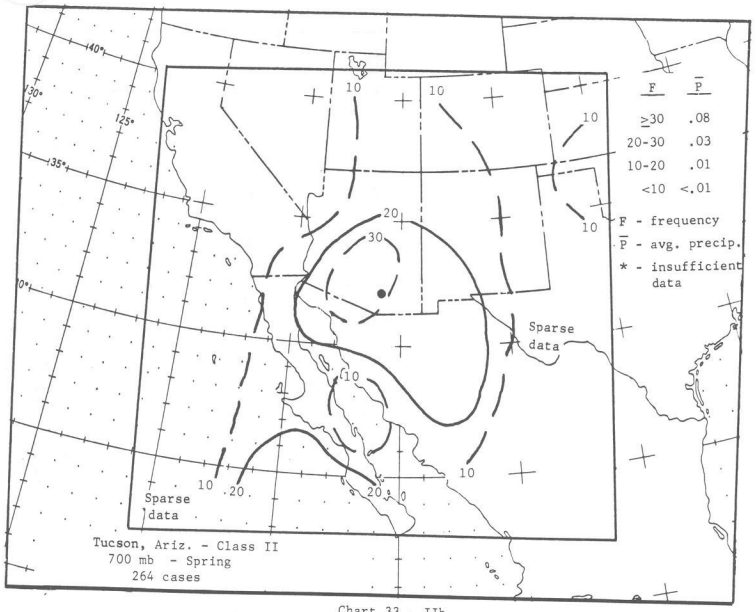



Chart 33 - IIb

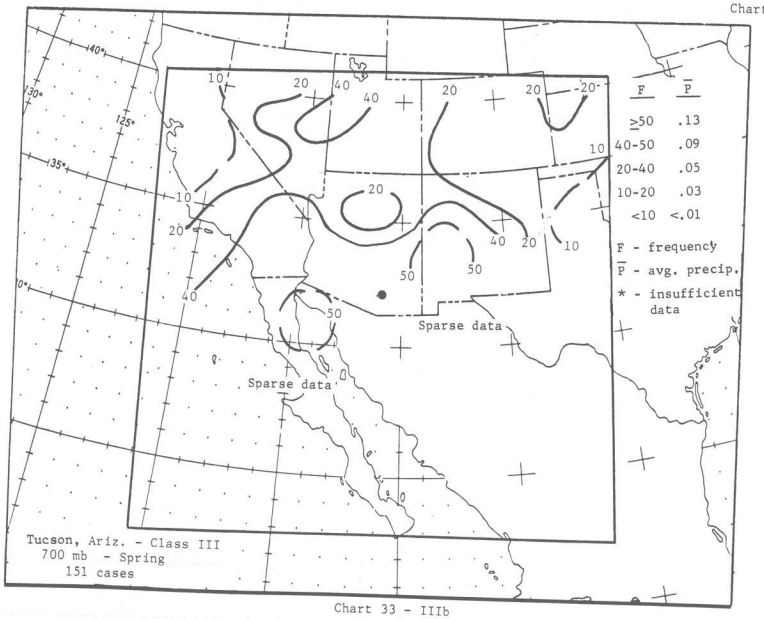



Chart 33 - IIIb

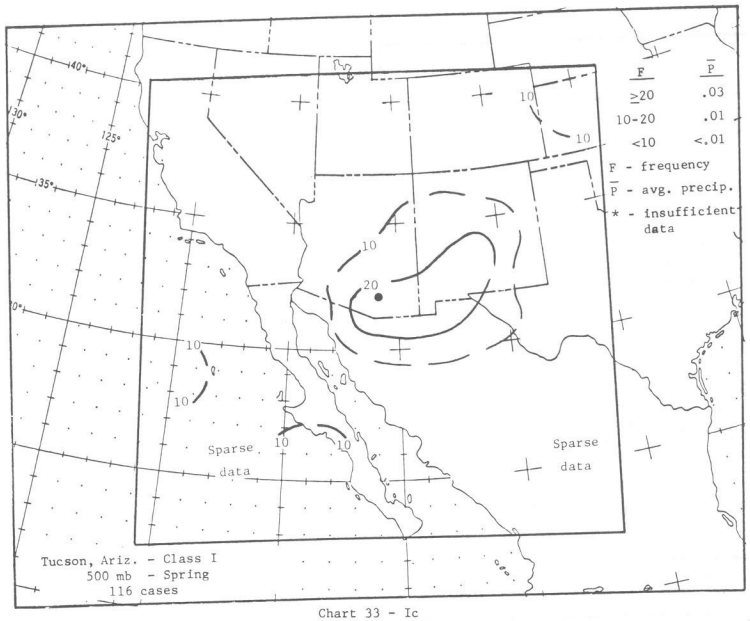



Chart 33 - Ic

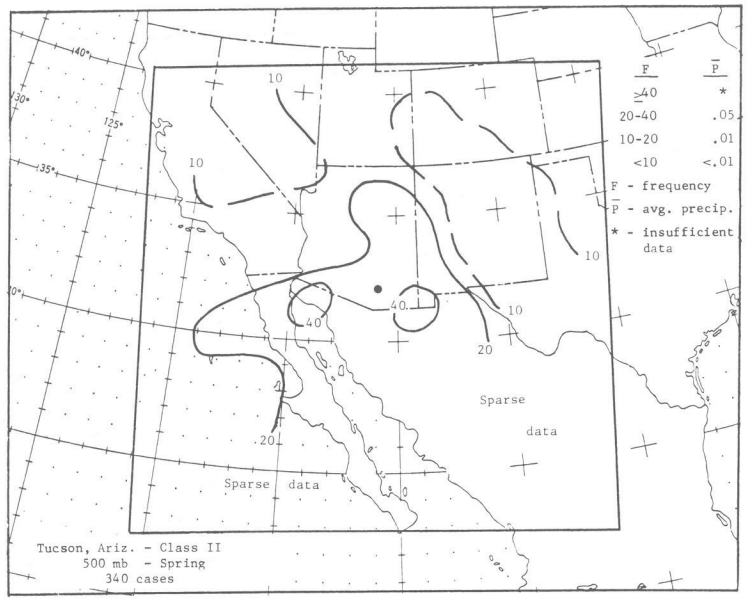



Chart 33 - IIc

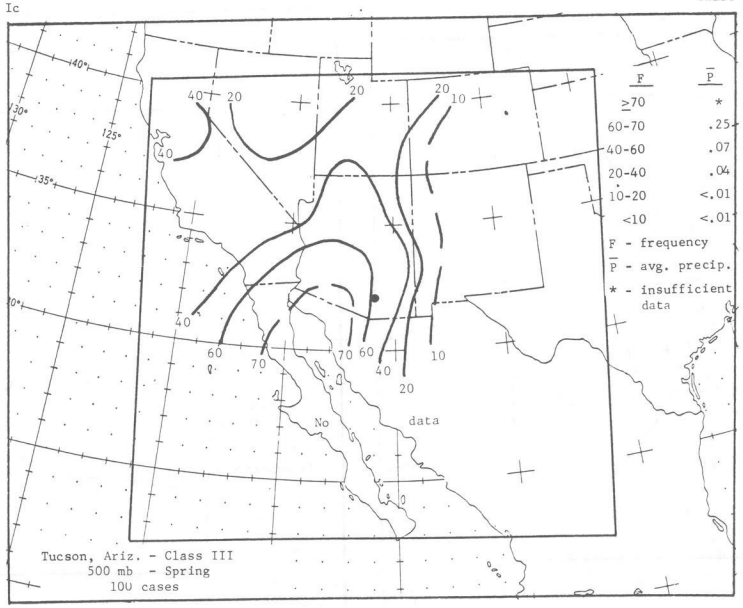



Chart 33 - IIIc

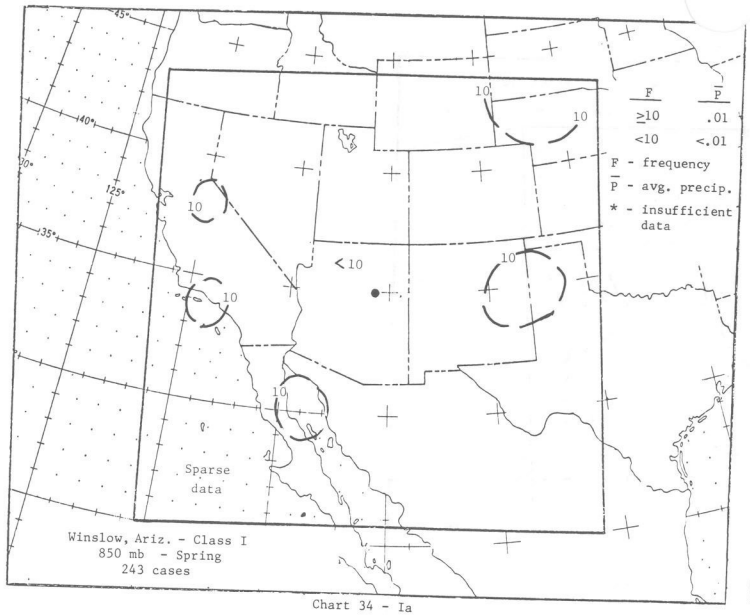



Chart 34 - Ia

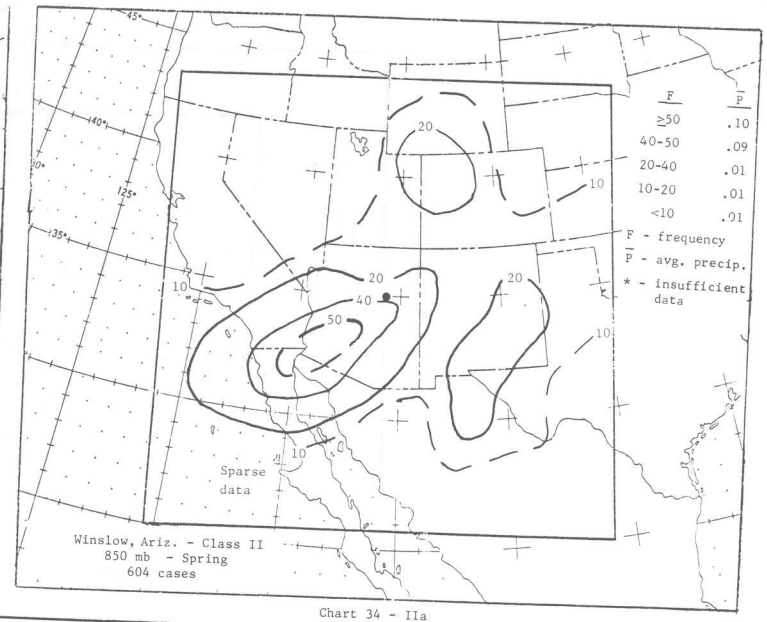



Chart 34 - IIa

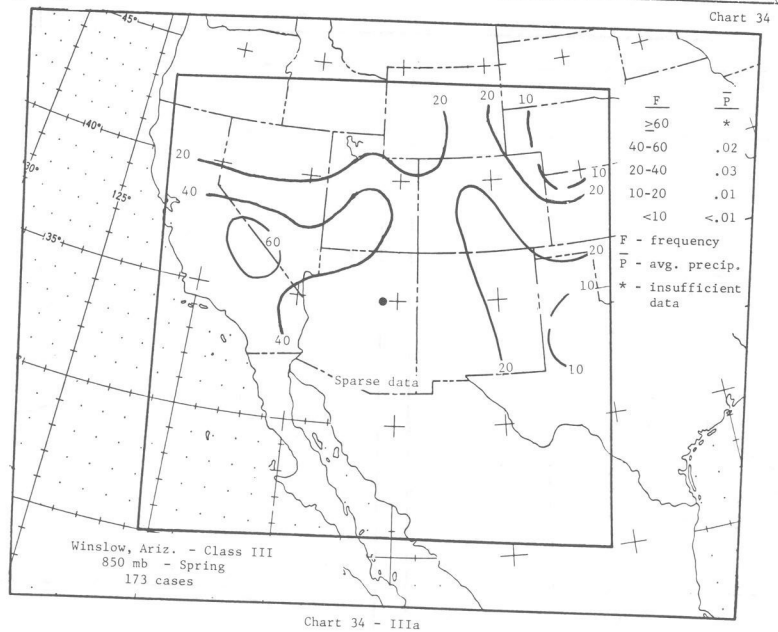



Chart 34 - IIIa

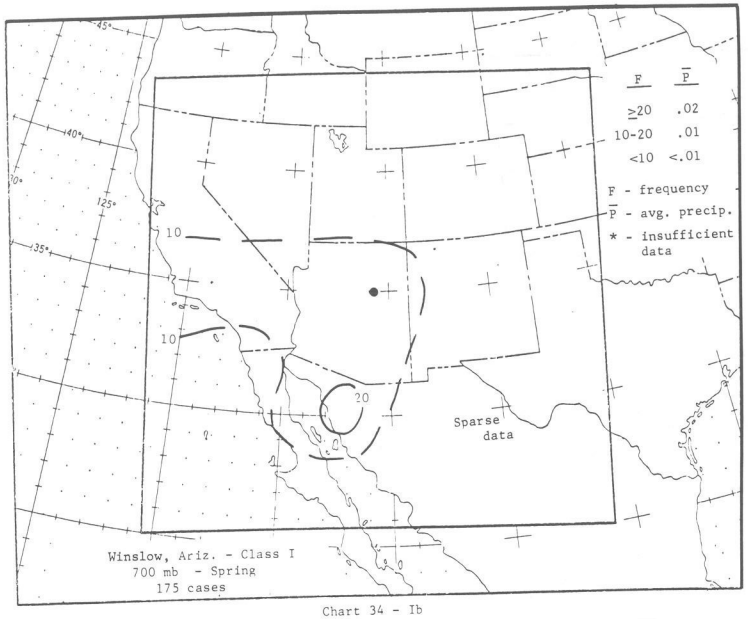



Chart 34 - Ib

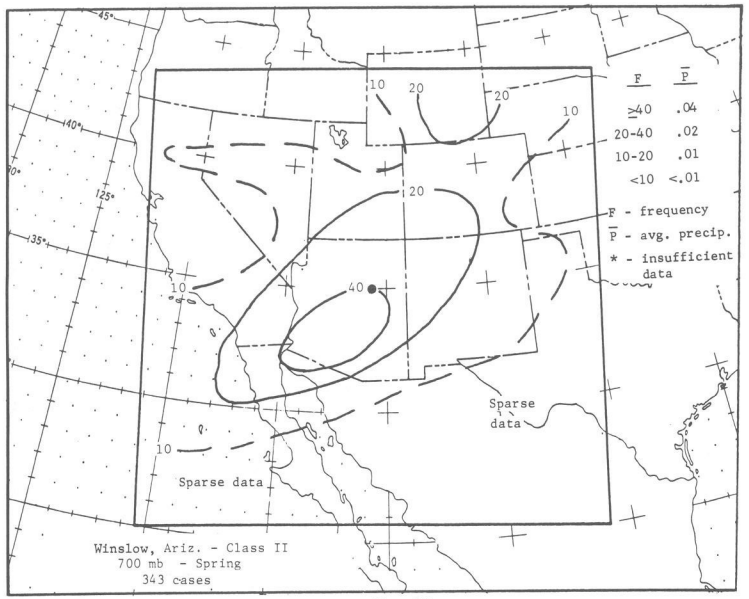



Chart 34 - IIb

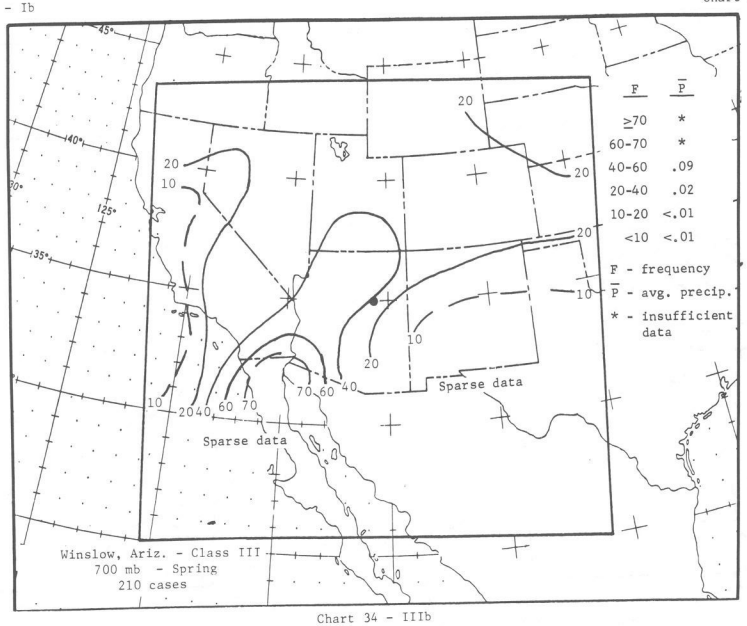



Chart 34 - IIIb

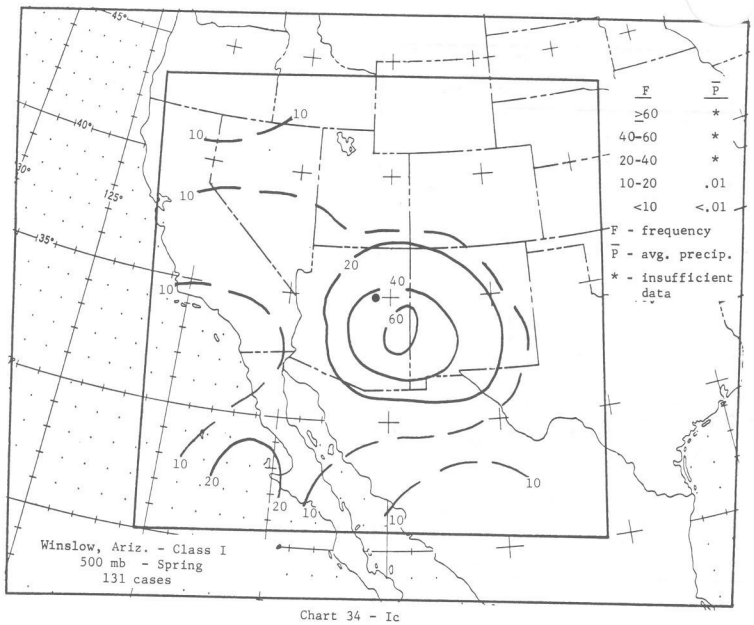



Chart 34 - Ic

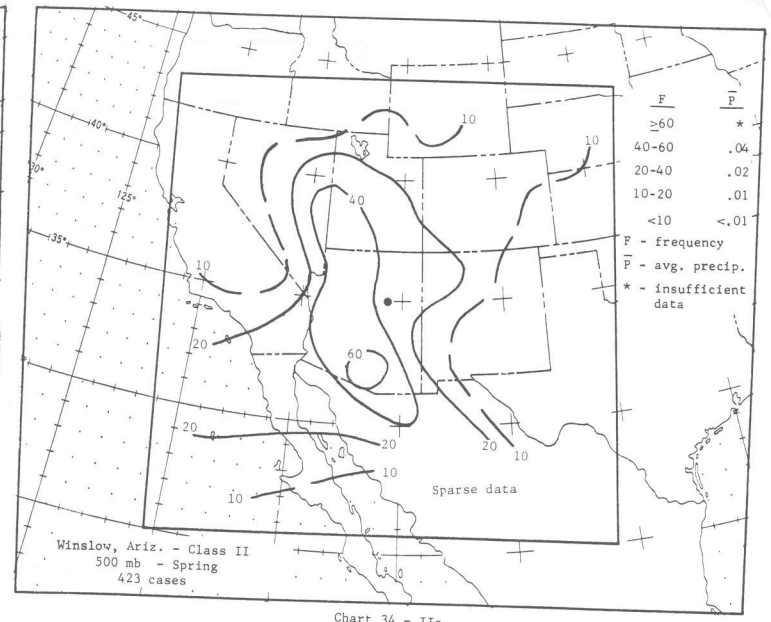



Chart 34 - IIc

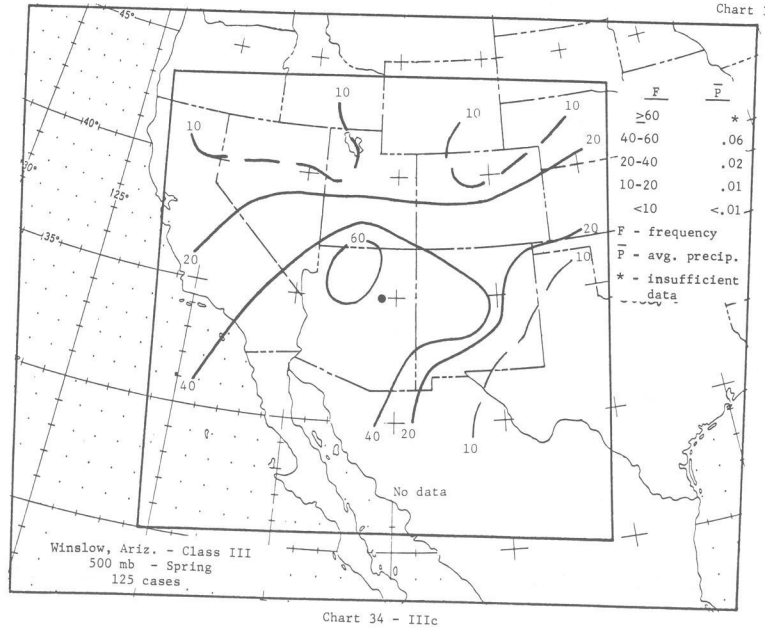



Chart 34 - IIIc

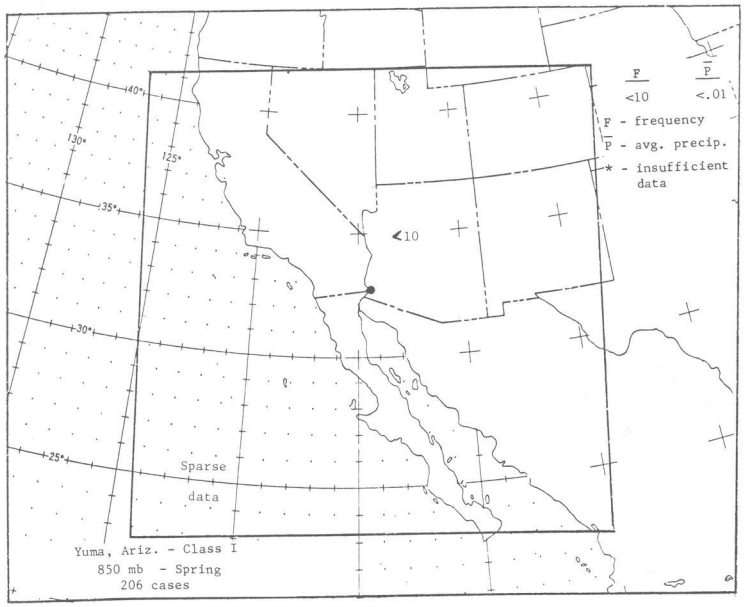



Chart 35 - Ia

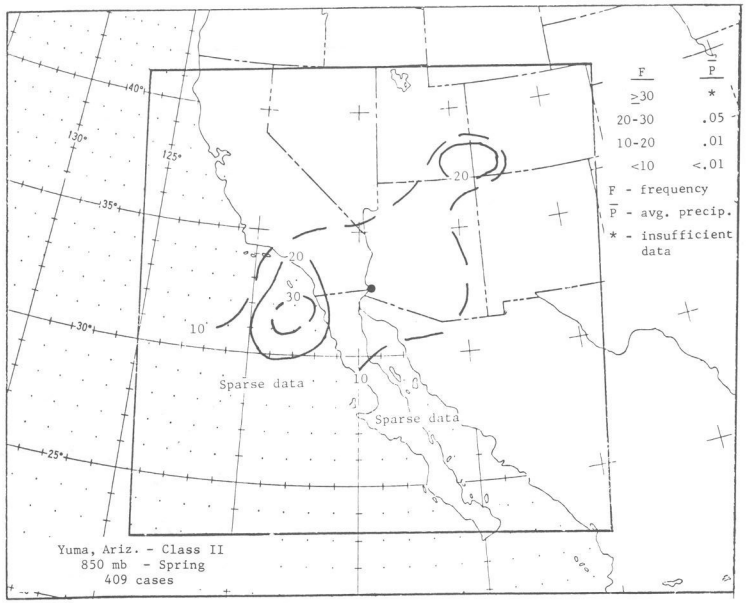



Chart 35 - IIa

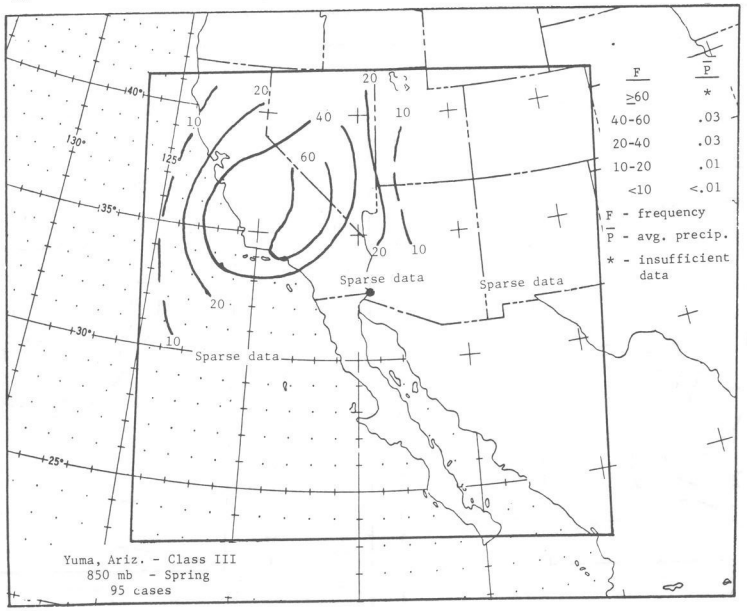



Chart 35 - IIIa

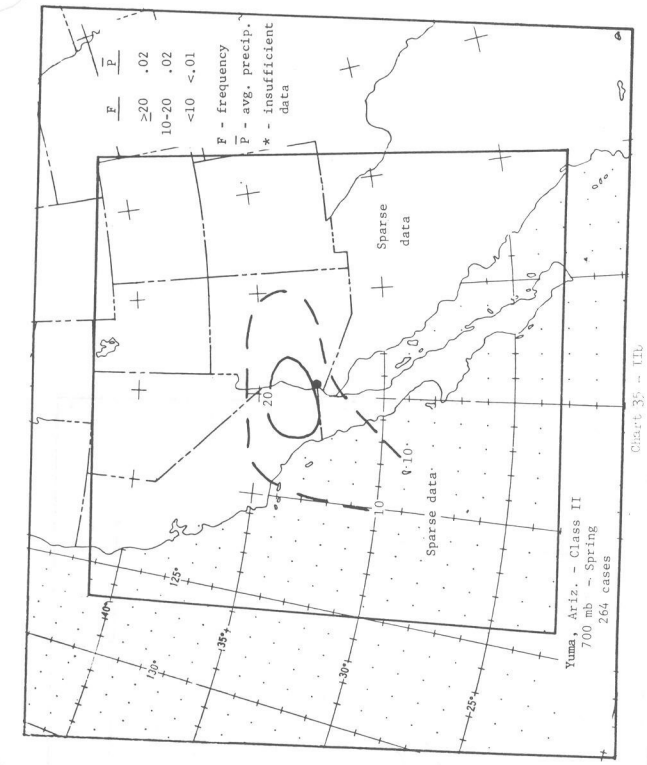



Chart 35 - IIb

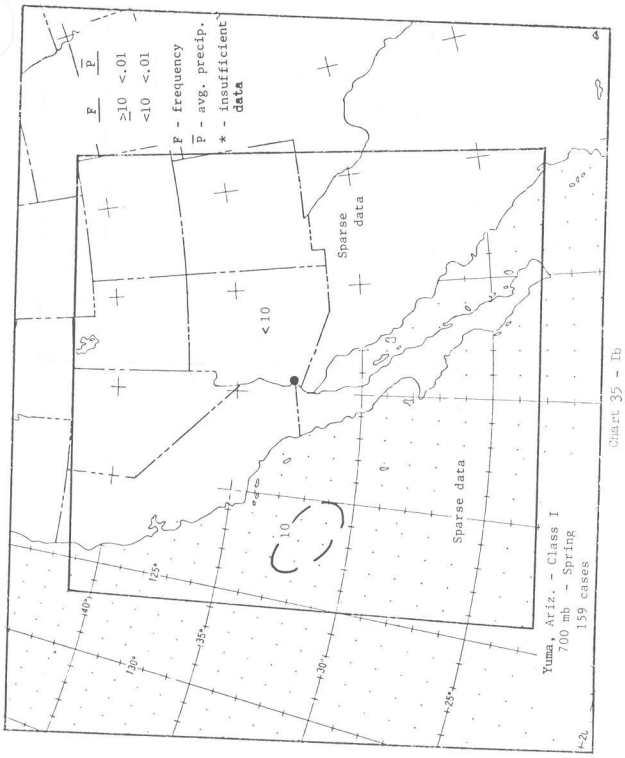



Chart 35 - Ib

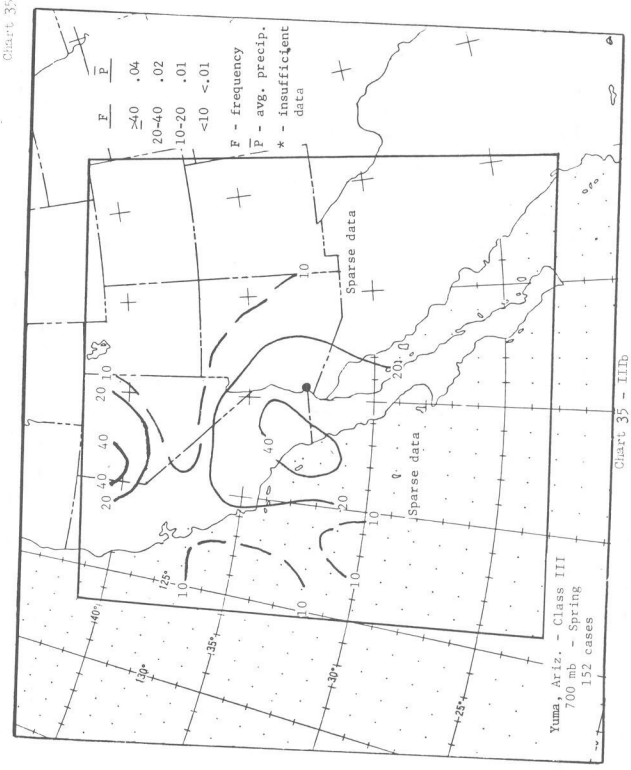



Chart 35 - IIIb

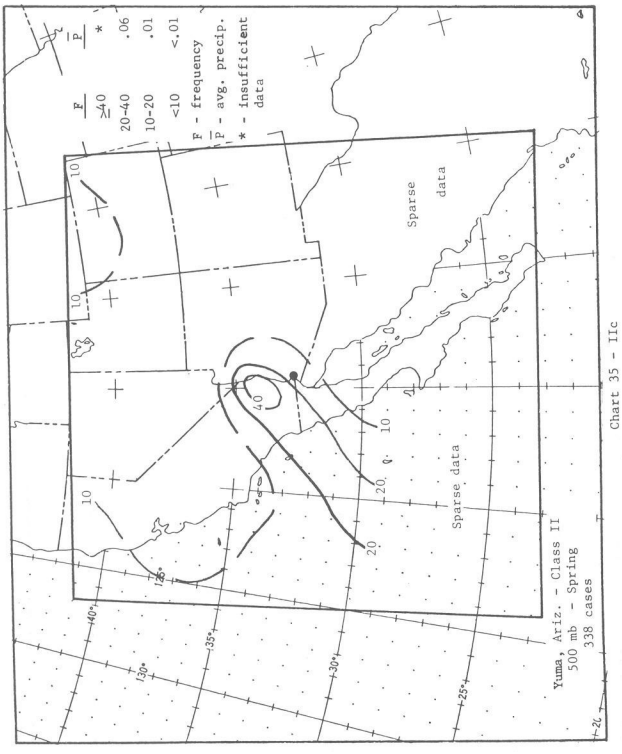



Chart 35 - IIc

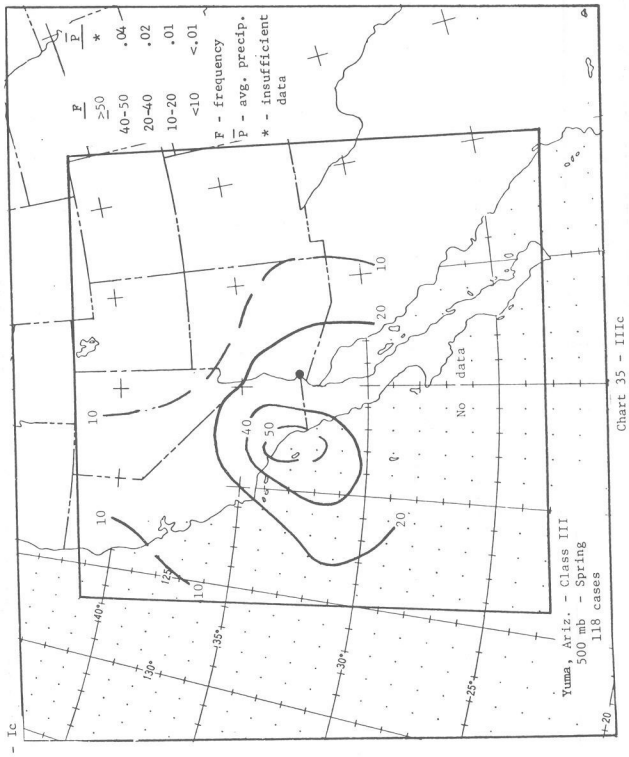



Chart 35 - IIIc

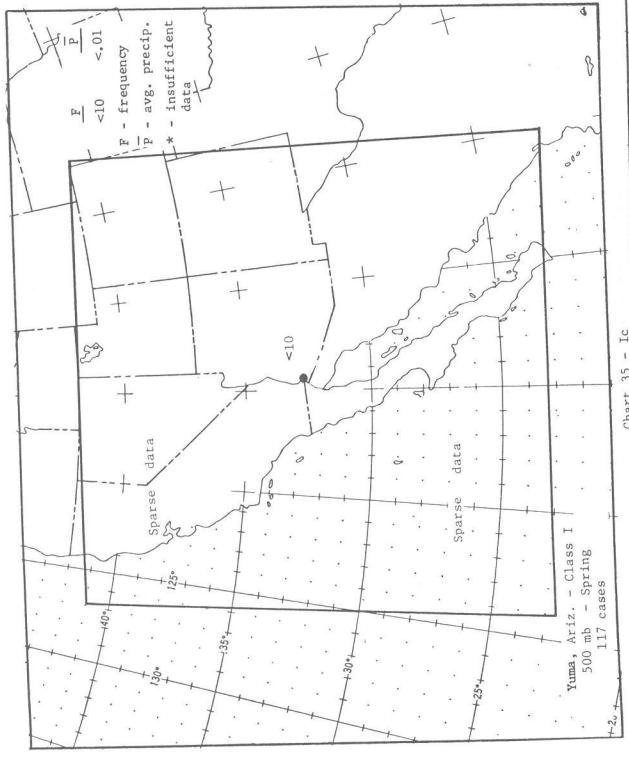



Chart 35 - Ic

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972—511-318 (51)

(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)

WBTM TDL 35 Probabilistic Prediction in Meteorology: a Bibliography. Allan H. Murphy and Roger A. Allen, June 1970. (PB-194 415)

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

NOAA Technical Memoranda

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.