U.S.DEPARTMENT OF COMMERCE • ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

TECHNICAL NOTE 45-TDL-4

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A Synoptic Climatology of Winter Precipitation from 700-mb. Lows for Intermountain Areas of the West

BASIC KNOWLEDGE
TECHNIQUES DEVELOPMENT LABORATORY
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TECHNIQUES DEVELOPMENT LABORATORY

REPORT NO.4

WASHINGTON,D.C.
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WEATHER BUREAU TECHNICAL NOTES

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A SYNOPTIC CLIMATOLOGY OF WINTER PRECIPITATION FROM 700-MB LOWS FOR INTERMOUNTAIN AREAS OF THE WEST

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ABSTRACT

A synoptic climatology of precipitation resulting from upper closed Lows is developed for the intermountain areas of the West for the winter months of December, January, and February. Precipitation amounts at about 280 stations for 12-hr. periods, centered at upper-air observation times and expressed as percentages of 7-day station amounts, are related to the positions of the Low centers at the 700-mb. level through the use of a moving grid system. The upper Lows are classified into three intensity categories according to the departure from normal of the central height. For each category the average precipitation amount, extent, and frequency of occurrence over the area of the grid system are presented. The area of maximum precipitation is found just southeast of the centers of intense 700-mb. Lows. As the intensity of the Low center decreases, not only does the frequency of precipitation diminish, but also the area of maximum frequency progressively shifts to positions south and west of the center.

1. INTRODUCTION

The weather of a region is one of its most important natural resources. To understand and to exploit this resource by whatever means is available requires a knowledge of the relationships between the predominant atmospheric circulations and the associated weather phenomena. Of major interest, especially in the western arid regions, are those atmospheric circulations responsible for supplying important amounts of precipitation. Precipitation occurring over rugged terrain can be considered as being made up of two components, that part which is a result of the dynamic mechanisms within the storm itself, and that part which falls out as a result of the orographic effects. These two components are not readily separated, but the dual concept leads to a clearer understanding of the observed precipitation distribution in mountainous areas.

Mountain ranges which lie across moisture-bearing winds will receive precipitation on the windward side, while the lee slopes may be in a rain shadow. Small mountain ranges and individual peaks all bring into play their unique effects on the precipitation distribution for a given storm. Charts giving the climatological distribution of precipitation [12] illustrate the complexity of the precipitation distribution in the West, largely as a result of the effects of the underlying topography (see fig. 1). Equally complex patterns may occur with individual storms in areas where orographic effects may be considered to be minor. However, when averaged for a sufficiently large number of storms, the pattern here becomes relatively smooth, as shown by the mean precipitation pattern over the Great Plains in figure 1.

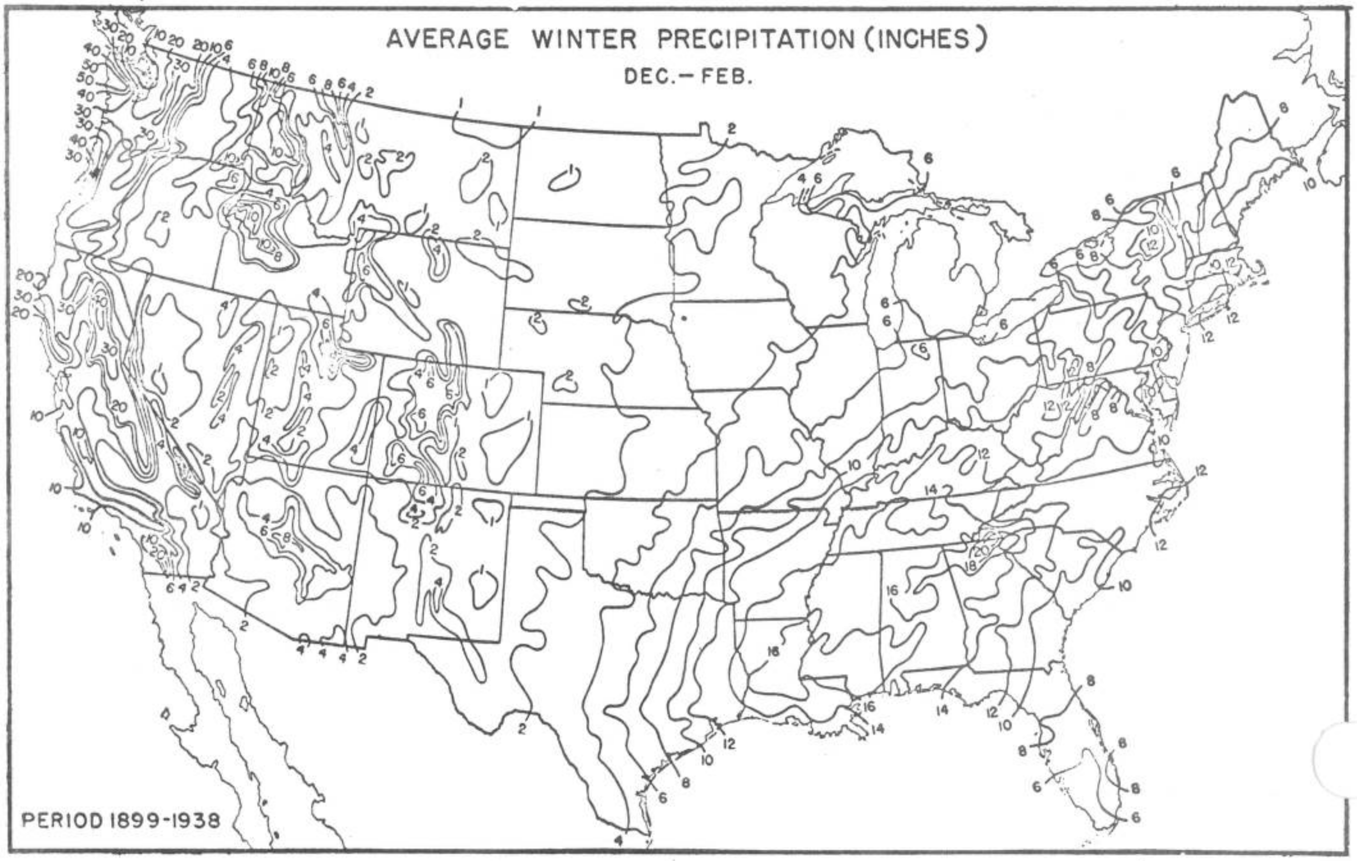


Figure 1. - Chart showing average winter precipitation (from Climate and Man [12]). Note complex precipitation distribution pattern in western intermountain region.

Characteristics of the atmospheric circulation exhibited by synoptic weather charts can be related to the associated weather to give a "synoptic climatology". Used in this sense, a synoptic climatology may be defined as the study and analysis of climate in terms of synoptic weather information [1]. Once a synoptic climatology has been developed, this information may then be used as a forecasting aid, given a prediction of the expected synoptic conditions, or as a tool for the analysis and study of individual storms. When used as an analytical tool, it can serve as a means for evaluating artificially induced weather effects.

Previous studies [4, 14, 15] have shown that storm systems characterized by cyclonic circulation aloft are one of the most important causes of precipitation in the western Plateau region. These systems, which are usually reflected on sea level charts in the form of disorganized low pressure systems, are mainly a phenomenon of the middle and lower troposphere but may frequently extend to higher levels. The dynamics of these systems can produce upward air motions resulting, over a wide area, in nonorographic precipitation which is then augmented, or diminished, by orographic factors. Although other types of synoptic situations may produce substantial amounts of precipitation, they will not be considered in this study.

The most significant level for the specification of weather is not generally agreed upon and undoubtedly depends upon the type of weather under consideration. Recently, Klein et al. [6] obtained a good relationship between existing weather and the concurrent daily 700-mb. circulation for the winter season in the conterminous United States. For many years the Extended Forecast Division of the National Meteorological Center, U. S. Weather Bureau, has placed main emphasis on the 700-mb. level [9, 10]. Furthermore, the 700-mb. circulation was found to be most useful when expressed in terms of height anomalies [5, 7, 8, 11]. In the present investigation, attention will therefore be focused on the 700-mb. level, with the intensity of the upper Lows expressed in terms of height anomalies or DN (departure from local normal) values.

It is the purpose of this investigation to develop, as part of the basic knowledge of weather in the western Plateau region, a synoptic climatology of winter precipitation resulting from upper closed Lows. This knowledge is a prerequisite to the proper understanding of weather systems which affect the area and is needed in order to form a basis for carrying out weather forecasting studies and planning efforts aimed at weather modification and climate control [2]. In the latter case, this knowledge can help to indicate when modification measures should be undertaken during an upper Low situation and can furnish a basis for a more effective evaluation of the modification efforts.

In developing a synoptic climatology for the specified area, the procedure makes full use of an electronic computer to derive the required relationships between synoptic information and the weather. In an interim report [13], the first phases of the investigation were described and the initial results from the computer printouts were given.

2. DEVELOPMENTAL DATA

The weather over the Plateau area begins to come under the influence of upper Lows while these systems are still at a considerable distance from the area. The Lows usually approach from a westerly or southwesterly direction, but occasionally may move in from the northwest or from the south. In addition, the upper Lows may form directly over the Plateau with no previous history of movement as identifiable Lows. The weather continues to be influenced by these upper systems as they move over the area.

(1) Upper Low Observational Area. - In order to insure that upper Lows would be brought into consideration by the time they become a threat to the Plateau region, especially in the southern portions, a broad area of data recovery was considered. This area included the region bounded by the latitude circles of 25°N. and 50°N., the 125°W. meridian, and the eastern borders of Montana, Wyoming, Colorado, and New Mexico and southward into Mexico along the 103°W. meridian, as shown in figure 2. Once the upper Lows entered this area, their effect on the weather over the Plateau was investigated.

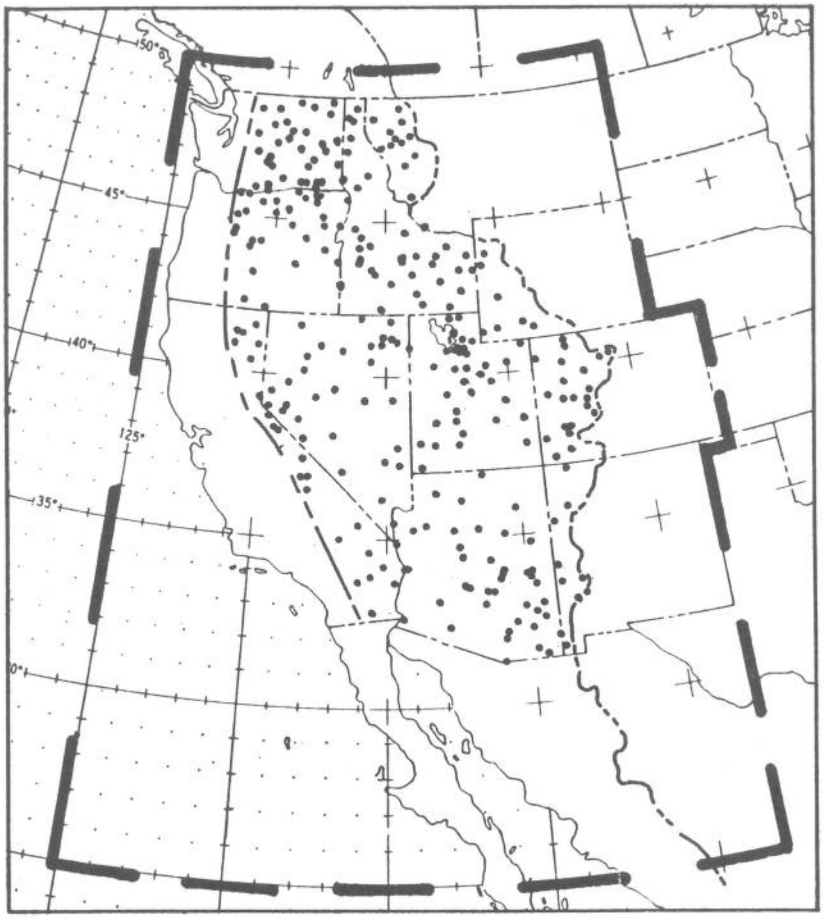


Figure 2. - Chart showing observational area (enclosed by heavy dashed lines) from which upper Low data were obtained and precipitation station network (black dots).

(2) Precipitation Reporting Network. - As the basis for investigating the precipitation associated with upper Lows, a network of stations for which hourly amounts were available was selected. The network is made up of stations which appear in the U. S. Weather Bureau climatological publication "Hourly Precipitation Data" and consists of about 280 reporting stations located in the area bounded by the Continental Divide to the east, the Cascades and the Sierras to the west, and the Canadian and Mexican borders to the north and south (see fig. 2.).

(3) Period of Record. - Data from the winter months of December, January, and February from December 1951 through February 1964 were used.

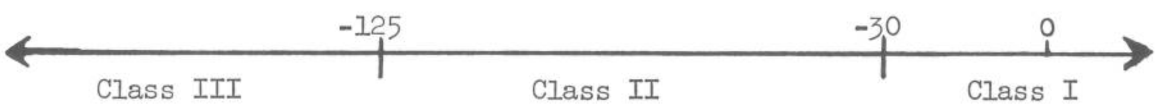
(4) Data Sources. - Positions and characteristics of upper Lows were extracted from microfilm copies of manuscript 700-mb. charts, prepared by the National Meteorological Center, Suitland, Md., from the 0000 and 1200 GMT observations. Prior to June 1, 1957, the observation times were 0300 and 1500 GMT.

Hourly precipitation data were recovered by the National Weather Records Center, Asheville, N. C., from their climatological file. Amounts for 12-hr. periods centered at the observation times were obtained for the situations involving upper Lows.

(5) Upper Lows and Their DN Characteristics. - Lows indicated by an "L" or "LOW" entered at the Low center appearing in the observational area on the original 700-mb. analysis were cataloged. A closed contour about the center was not required for the identification of the center. Positions of the Lows were recorded in degrees and half degrees of latitude and longitude. Occasionally more than one Low existed in the observational area at the observation time. When this occurred the major Low was classified as predominant, depending on whether it was the deepest Low present or the most persistent on successive maps. For the 13 years considered, 645 major Lows were identified, with about equal numbers occurring on an average during the three winter months.

Among the characteristics of the Lows which were investigated, the departure of the observed height from the normal height for the month and central position of the Low was found to have considerable significance in determining the areal extent of precipitation and the quantitative amounts to be expected from the upper Lows. Accordingly, the cases involved in the study were grouped into three classes depending on the DN values (observed minus local normal height) of the 700-mb. heights of the cyclonic centers. A histogram of the frequency of occurrence of DN values for all cases showed a rather symmetrical distribution about the central value. Intensity classes were defined in such a way as to give three nearly equal ranges of DN values. The ranges of these classes are shown schematically on the following scale:

Departure from Normal (DN values)



Class I included 180 Lows for which the central heights ranged from above normal to 30 meters below normal, Class II included 314 Lows for which the central height ranged from 30 to 125 m. below normal, and Class III was made up of 151 Lows with central heights 125 m. or more below normal. (The normal charts and the procedure for obtaining the DN values are given in Appendix A.) This approach takes into account the substantial latitudinal variation in the normal 700-mb. height pattern as well as the somewhat smaller longitudinal and monthly variations.

3. MOVING GRID SYSTEM USED TO DEVELOP SYNOPTIC CLIMATOLOGY

An earlier study by Jorgensen [3] describes a means by which a moving grid can be used to derive a synoptic climatology through the use of an electronic computer. The required input consists of the weather element for a network of reporting stations of known positions in terms of latitude and longitude and the location (again in terms of latitude and longitude) of a characteristic point of a storm system about which the distribution of the weather element is being investigated. A description of the mathematical development used in the computer program is given in Appendix B. The same computer program which was used in the original study was used by the National

Weather Records Center (NWRC) at Asheville, N. C., to derive the present synoptic climatology.

The National Weather Records Center was furnished the dates and observation times of the tabulated Lows, together with the latitude and longitude of each Low and its central DN value. Precipitation data for 280 observing stations were extracted from their records by NWRC for the required 12-hr. periods centered at observation times.

In the development of a synoptic climatology of precipitation for an area under strong orographic influence, the precipitation can be expressed in terms of a specified normal amount for each reporting station. This tends to minimize the variation of precipitation amounts due to orographic effects when a final summarization of the data is made. The precipitation data expressed in this manner, and the positions of the 700-mb. Lows classified according to their DN values formed the basic information, which was processed by computer according to the existing program to generate the results given in this report.

The precipitation parameter, the grid system employed, and the form of the results obtained are described in the following sub-sections.

(1) Precipitation Parameter. - For the purposes of this study, the precipitation was expressed as a ratio of the observed amount to a normal amount expected for a 7-day period for the given month. Thus,

$$R = \frac{A_o}{7 \frac{M}{n}}$$

where

R = precipitation parameter (in percent when multipled by 100),

A_o = observed precipitation at station for 12-hr. period,

M = normal monthly amount,

n = number of days in given month.

Normal amounts by months were derived by NWRC for the 280 stations. A period of record of 10 years was used in making up the normals except for a few stations where 10 years of record was not readily available. In a few instances, especially in the desert areas, where the period of record used was not sufficient to give a valid station normal when compared with existing averages for longer periods, a new "normal" was substituted based on longer climatological records.

(2) Grid System. - The grid network was made up of a nearly rectangular area 18° of latitude on a side with the grid lines coinciding with great circles on the surface of the earth. This grid is shown in figure 3. The great circles are 1° of latitude apart along the abscissa and ordinate, thus

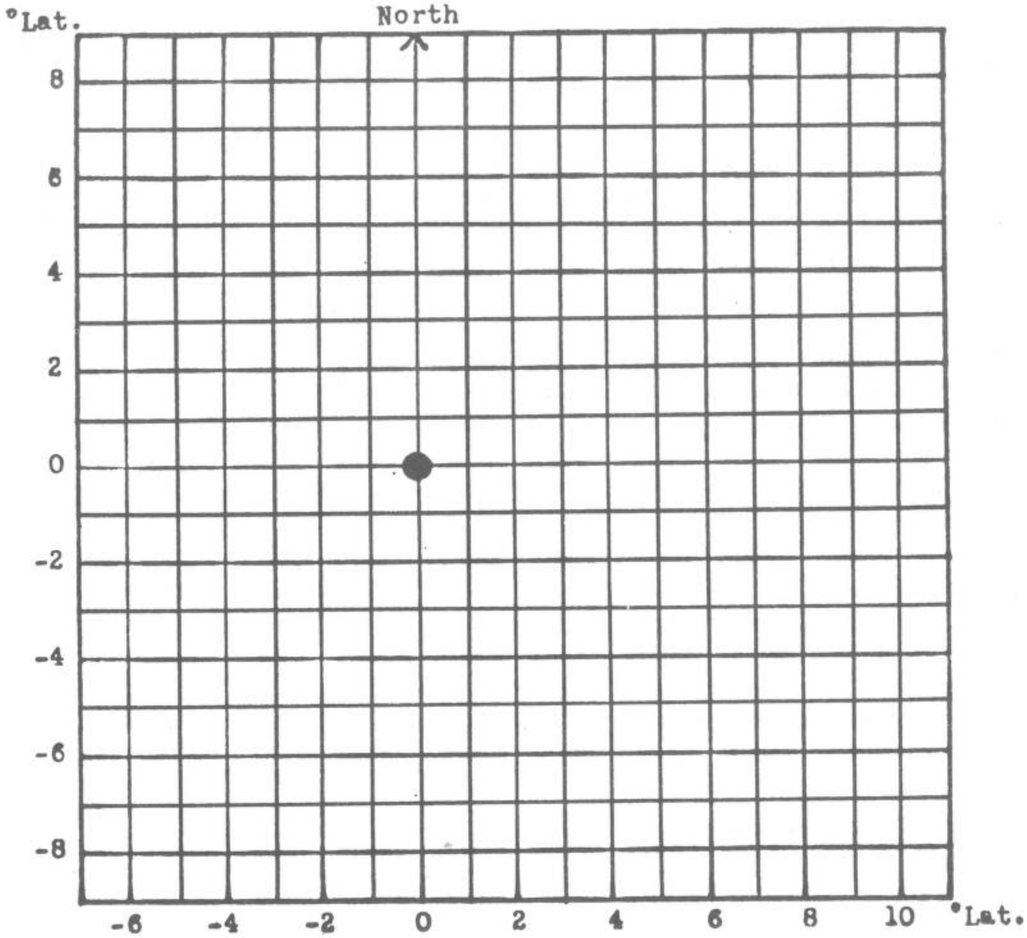


Figure 3. - Grid representation on plane surface. Grid system consists of great circles on the spherical earth with dimensional units equivalent to latitude degrees along the two axes. Origin of grid (●) is displaced 2° toward the "west" because greater rain areas can be expected to the east of the upper Low center.

making up a network of 324 cells essentially 1° latitude square. This grid permitted the development of a computer program which could scan the amounts reported by the observing stations and allocate these amounts to the correct cell. When more than one report fell within a cell, an average value was computed for the cell. These values were then considered to be located at the center of the grid cell.

The grid system defined in this manner does not coincide with either the longitude or latitude lines on a surface chart, with the exception of the north-south line through the origin which coincides with the longitude line through the same point. Practical use of the derived results can best be made through the use of a surface chart based on the Lambert Conformal projection. On this type of chart, great circles, the lines making up the grid system, appear very nearly as straight lines. Thus, a rectangular area drawn on this chart represents nearly the same area when drawn to the correct scale and orientation as that of the grid system.

The computer program as originally developed has the capability of rotating the grid system about the origin. For the present study, however, the system was oriented with the ordinate in a north-south direction, i.e.; with a zero rotation angle.

(3) Machine Printouts. - The machine program was written to give printouts of the individual situations and summarizations for each grid cell of the mean precipitation value (average of the percentages of the 7-day station normals), the number of times precipitation was recorded in the cell, and the resulting frequency of amounts (with amounts expressed as percentages of 7-day normals) for eight categories for the three DN classifications of the upper Low situations. These data were used to produce the charts giving the results of this investigation.

4. DERIVED SYNOPTIC CLIMATOLOGY OF PRECIPITATION

The synoptic climatology obtained from this investigation has been expressed in the form of charts showing the quantitative values and the frequencies of precipitation recorded in each grid cell in relation to the position and DN value of the upper Low at the 700-mb. level. These charts have been obtained from the analysis of the computer summarizations and are presented in the following sections. The amount of data going into the various analyses is given in Appendix C.

(1) Average Precipitation Amounts from Upper Lows. - The analysis of amounts expressed as percentages of 7-day station normals is given for each grid cell for 12-hr. periods centered at the upper-air observation times in figures 4 through 6 for each of the three DN classifications.

Figure 4 gives the average amounts which can be expected to occur during the 12-hr. period centered at the time when the 700-mb. Low is located at the origin (solid dot) for Class I Lows. This is the least intense class of Lows and includes those which have a central height of from 30 m. below normal to values above normal ($DN \geq -30$ m.). As shown by the figure, this class of Lows results in very light precipitation, with only scattered areas showing as much as 10 to 20 percent of the 7-day normals.

Figure 5 gives results similar to the preceding figure but for Class II Lows, which are of moderate intensity as measured by the DN values. Lows in this class have central heights between 30 and 125 m. below normal ($-30 > DN > -125$). As indicated by this chart, the area with amounts in excess of 10 percent has increased considerably, and local areas with as much as 35 to 40 percent of the 7-day normal are located several degrees to the east and south of the low center. Little or no precipitation is reported within the grid network in the northern and western portions or in the southeastern corner.

A similar analysis for Class III Lows is given in figure 6. This class is made up of only the most intense Lows with DN values greater than 125 m. below normal. As shown by this figure, the areas of heavier precipitation are larger than for the less intense classes, with several areas above the 60 percent level. Heaviest amounts occur in an area centered about 2° latitude distant from the upper Low center in the northeast and southeast quadrants. Another area of heavy precipitation is shown in the southwestern corner

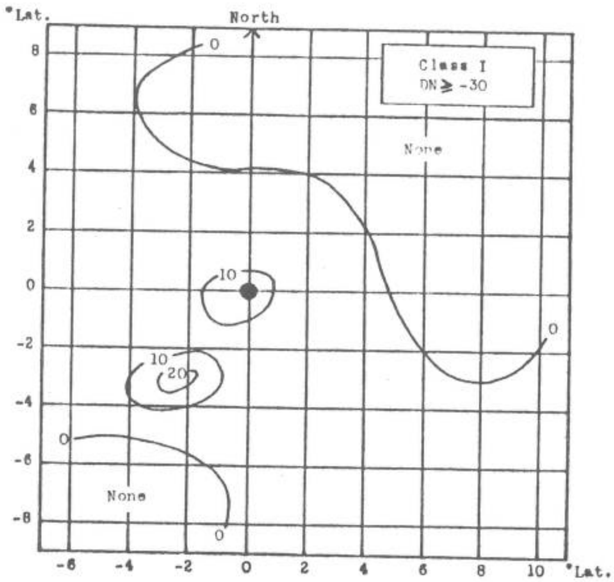


Figure 4. - Analysis of average amounts of precipitation for Class I Lows. Amounts during the 12-hr. period centered at upper-air observation times are expressed as a percentage of 7-day station normals. Upper Low is centered at origin (●) with grid network as given in figure 3.

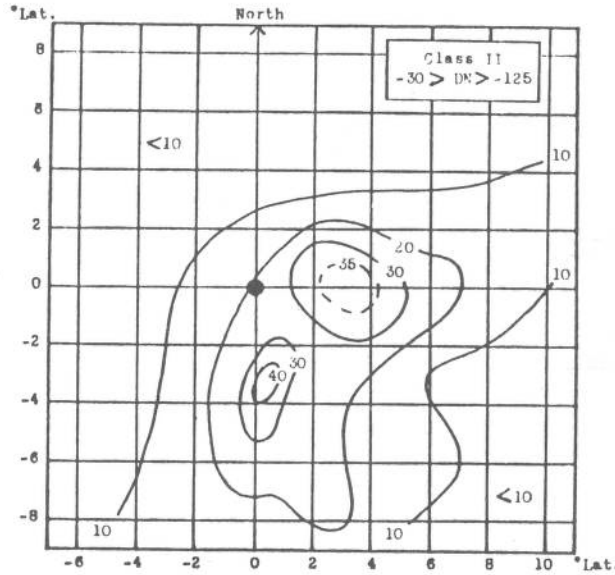


Figure 5. - Same as figure 4 except for Class II Lows.

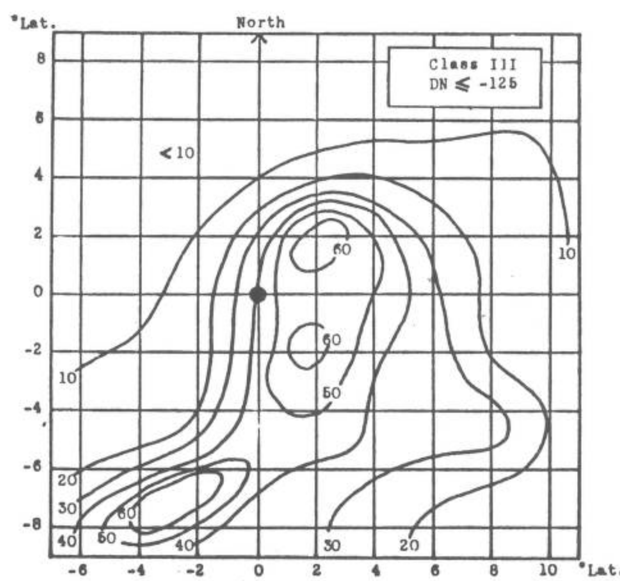


Figure 6. - Same as figure 4 except for Class III Lows.

of the grid network. This latter area does not show up in a similar manner on the other charts, but is believed to be a true representation of the more intense systems, although based on a relatively small number of cases.

(2) Frequencies of Precipitation from Upper Lows. - The computer print-out furnished frequencies of amounts (expressed as percentages of 7-day normals) in eight categories: 0, 0-10, 11-25, 26-50, 51-100, 101-200, 201-400, and over 400 percent. In order to increase the significance of the analyzed charts, the number of observations per chart was increased by combining the eight categories into four. The combined categories were 0, 1-25, 26-100, and over 100 percent. The frequencies of precipitation recorded in each of these categories were then analyzed for each of the three DN classes, giving charts showing the frequencies of measurable amounts (amounts greater than 1 percent) and frequencies in three quantitative categories. Although expressed in terms of frequencies, figures 7-9 can be interpreted as probabilities when used to indicate the likelihood of the future occurrence of precipitation.

Figure 7 shows the frequencies of amounts equal to or greater than 1 percent of the 7-day normal during 12-hr. periods centered at observation times for the Class I Lows. An area of from 20 to 25 percent frequency is centered to the west and southwest of the position of the upper Low center. Elsewhere over most of the grid system, frequencies are below 10 percent, with the exception of a band surrounding the 20 percent area and extending toward the southeast. A second 20 percent area appears in the extreme southeastern corner of the grid, but it is not believed that these cases are directly associated with the upper Low. They appear to be due more to low-level developments, and, in at least one instance, to cyclogenesis to the southeast of the upper Low.

A similar analysis is shown in figure 8 for the Class II Lows. Only along the northern boundary of the grid and over a small area in the extreme southeast is the frequency of occurrence below 10 percent. Frequencies of over 40 percent occur in an area to the east and south of the low center, with the maximum of around 55 percent occurring about 5° almost due south of the center.

An analysis of the Class III Lows is shown in figure 9. All areas of the grid exhibit a frequency greater than 10 percent, with most areas exceeding 20 percent. An area of greater than 60 percent exists in the vicinity of the Low center and extends toward the southeast, with local centers slightly in excess of 80 percent about 2° and 6° to the southeast of the upper center. Thus, it is seen that as the intensity of the Low centers increases, not only does the frequency of precipitation increase, but also the area of maximum frequency shifts from a position southwest of the upper center (fig. 7) to a position essentially south of the center (fig. 8) and then to the southeast of the center (fig. 9).

Figures 10 through 15 show the frequencies of occurrence for Classes II and III broken down into three quantitative precipitation categories. Class I has not been broken down further since the frequencies were already generally less than 10 percent.

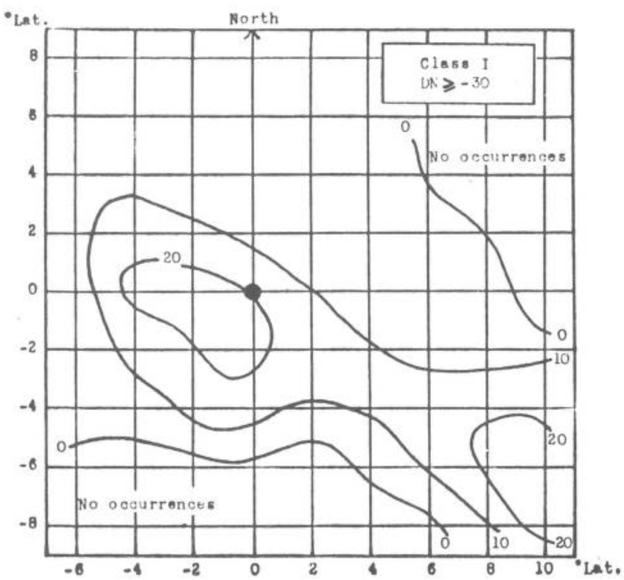


Figure 7. - Analysis for Class I Lows of frequencies of occurrence of precipitation amounts equal to or greater than 1 percent of the 7-day normal (essentially measurable amounts) in the 12-hr. periods centered at upper-air observation times.

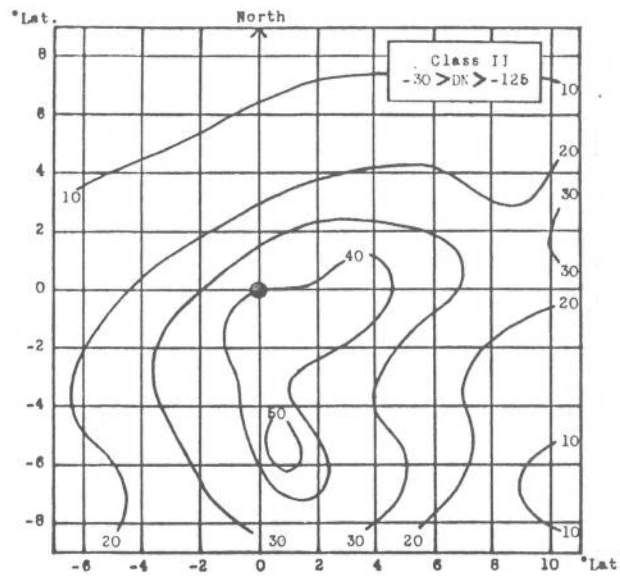


Figure 8. - Same as figure 7 except for Class II Lows.

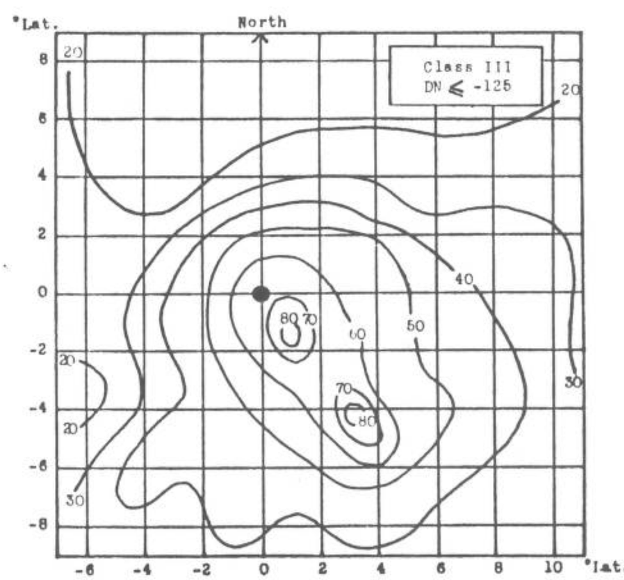


Figure 9. - Same as figure 7 except for Class III Lows.

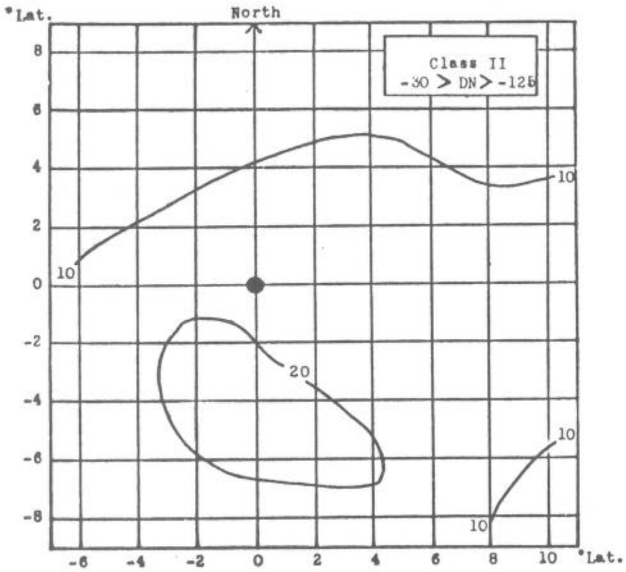


Figure 10. - Analysis for Class II Lows of frequency of occurrence of precipitation amounts from 1 to 25 percent of the 7-day normal in the 12-hr. periods centered at upper-air observation times.

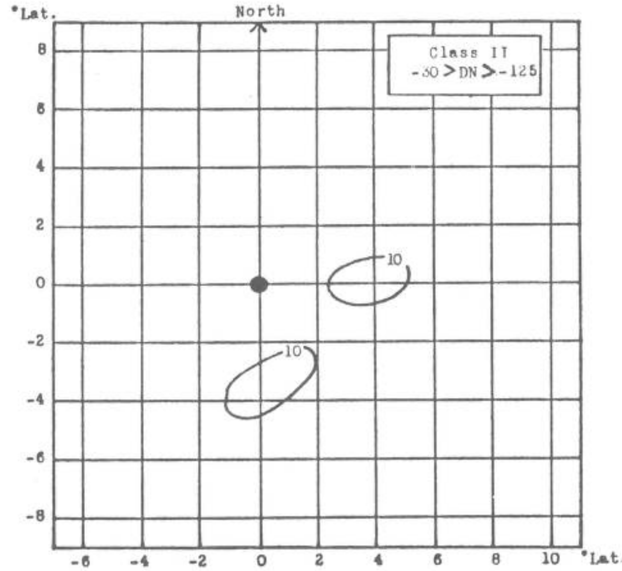


Figure 12. - Same as figure 10 except for amounts greater than 100 percent of the 7-day normal.

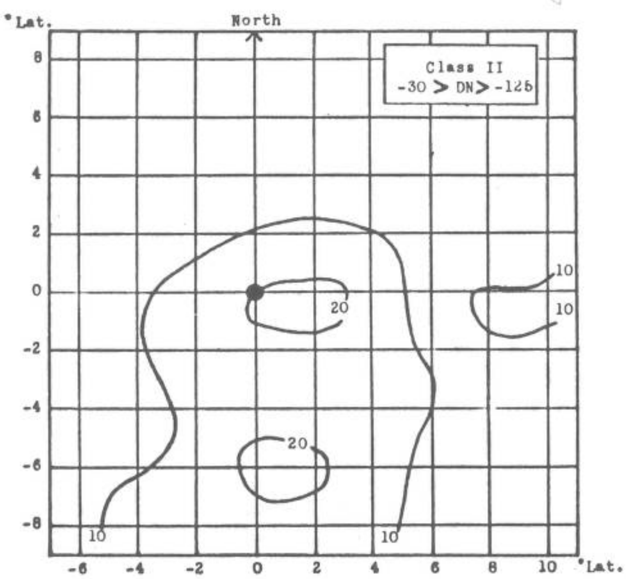


Figure 11. - Same as figure 10 except for amounts from 26 to 100 percent of the 7-day normal.

Figures 10, 11, and 12 give the analysis of amounts in three categories for the Class II Lows. As shown by these charts, the area with frequencies of 10 percent or higher decreases sharply with increasing amounts. For the light precipitation category, an area with frequencies of slightly over 20 percent appears to the south of the upper center (fig. 10). This breaks into two isolated areas for the intermediate amounts (fig. 11), and disappears completely for the heaviest amounts (fig. 12).

Figure 13, 14, and 15 show similar analyses for the Class III Lows. For the lightest precipitation category, all areas of the grid show frequencies greater than 10 percent, with an area greater than 20 percent extending diagonally across the grid

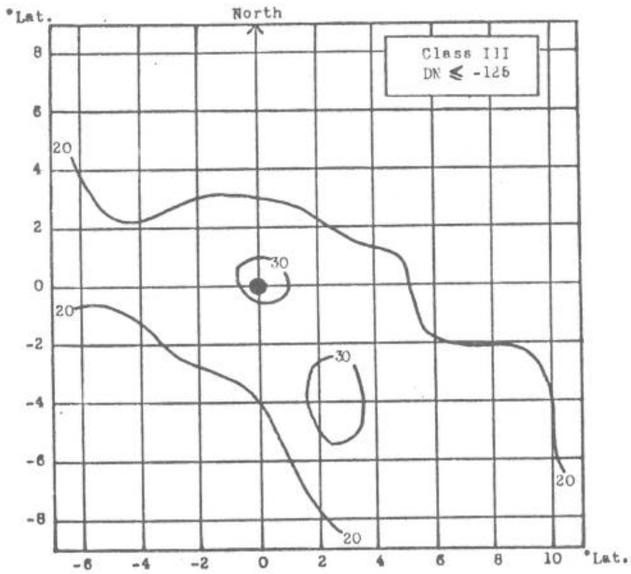


Figure 13. - Analysis for Class III Lows of frequency of occurrence of precipitation amounts from 1 to 25 percent of the 7-day normal in the 12-hr. periods centered at upper-air observation times.

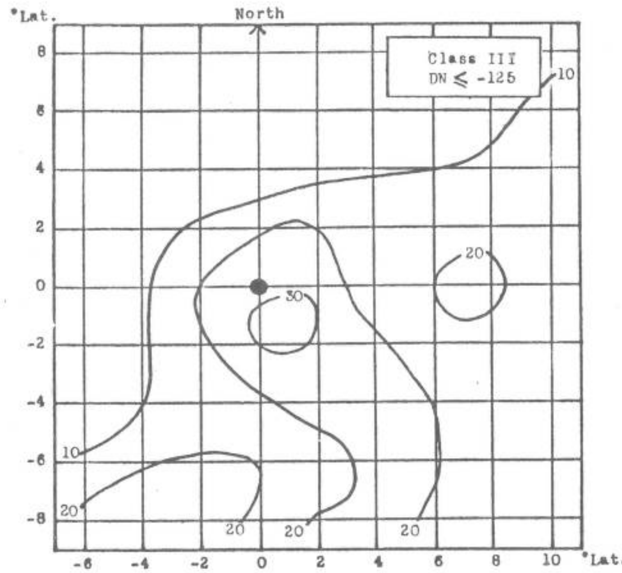


Figure 14. - Same as figure 13 except for amounts from 26 to 100 percent of the 7-day normal.

from the northwest toward the southeast (fig. 13). Small local areas in excess of 30 percent appear near the Low center and to the southeast. For the intermediate category (fig. 14), frequencies drop to below 10 percent along the western and northern boundaries of the grid but remain above 20 percent in the vicinity of the upper center and toward the south. A small area in excess of 30 percent continues just to the south of the center. For the heaviest category (fig. 15), much of the area has dropped to below 10 percent, but with two small areas of 20 percent values.

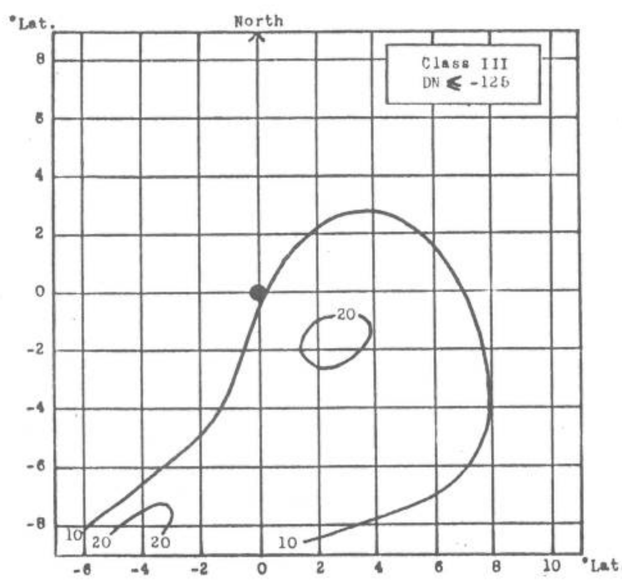


Figure 15. - Same as figure 13 except for amounts greater than 100 percent of the 7-day normal.

5. SUMMARY

Positions of 645 Lows were combined with the associated precipitation to develop a synoptic climatology of winter precipitation for the intermountain region of the West. The upper Lows were classified into three intensity categories depending upon the departure of the central height of the Low from the local normal (DN values). In order to smooth the derived precipitation patterns, precipitation amounts were expressed as percentages of 7-day normals, thus, in effect, eliminating much of the variability caused by the underlying topography. The derivation of the synoptic climatology was carried out by an electronic computer.

The output of the computer was analyzed to give charts showing the mean 12-hr. precipitation amounts (in percent of 7-day station normals) centered at upper-air observation times for the three DN intensity categories. Precipitation from the upper Lows was analyzed to show frequencies of occurrence of measurable amounts for the three DN intensity categories, and also for several precipitation intensity classes for the more intense Lows.

Precipitation was found to vary in its area of occurrence relative to the center of the Low and also quantitatively with differing intensities of the Low center. For the least intense class of Lows, the precipitation tended to occur near and to the southwest of the upper Low center. For moderately intense Lows, the precipitation area expanded and shifted to the south and east of the low center, with centers of maximum precipitation located about 3° latitude to the east and between 3° and 4° to the south of the center. For the most intense category, the area of heavier precipitation expanded still farther. For this category, an area of heavy precipitation, ranging up to 60 to 65 percent of the 7-day normal, was located at a distance of about 2° from the center in the eastern quadrant of the storm, with an additional area of heavy precipitation making its appearance in the extreme southwestern corner of the grid area.

Frequencies of occurrence of precipitation also were found to vary relative to the Low center with the changing intensity of the Low. For the least intense Lows, maximum frequencies up to 25 percent were observed to the west-southwest of the center. For increasing intensities, the area of most frequent occurrence expanded and migrated to the south and then to the southeast of the low center. Maximum frequencies of about 80 percent were obtained for the most intense storms for limited areas just to the southeast of the center.

The derived synoptic climatology can be a valuable aid to the weather forecaster in the West during the existence of upper Lows (or prior to their development when accurately predicted) to gain a first estimate of the amount of precipitation expected to result from this type of storm. When used as a forecasting tool, the frequency of occurrence indicated by this study can be used as a first estimate of the probability of receiving precipitation at individual stations, given the expected position and intensity of the 700-mb. Low from numerical forecasts routinely transmitted over facsimile. In a similar manner, the derived synoptic climatology can serve as basic information for studies aimed at investigating weather modification and climate control in the area covered by the study.

It is planned to expand this investigation by using other levels of the troposphere, e.g., 850 mb., 500 mb., and 300 mb., in addition to the 700-mb. level used thus far. A synoptic climatology will also be derived for other circulation characteristics, such as vorticity, thickness, or advection centers. Furthermore, the NWRC computer program will be reversed by running with individual stations at the center of the grid, so that graphical forecast aids will be obtained for local application. Later, multiple regression equations will be derived for objectively specifying precipitation at individual stations. Finally, the entire study will be extended from winter to the other three seasons of the year.

6. ACKNOWLEDGMENTS

This investigation was accomplished through the financial support of the Bureau of Reclamation, Department of Interior. Data accumulation and data processing were carried out by the National Weather Records Center, Asheville, N. C., yielding computer output and summarizations on which analyses of the synoptic climatology charts were based.

APPENDIX A

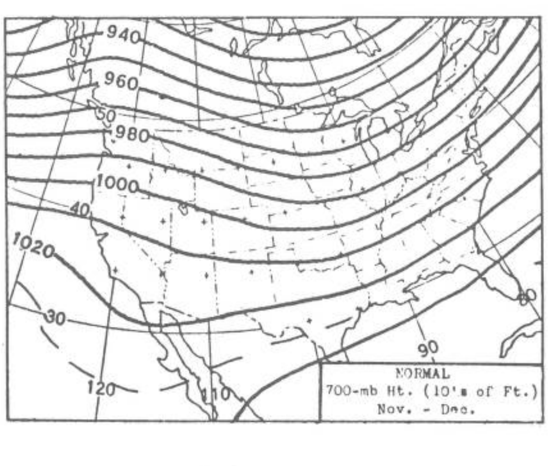
PROCEDURE FOR DETERMINING DN CLASSIFICATION OF UPPER LOWS

The 700-mb. Lows used in this investigation have been classified according to the departure from normal of the central height. Normal charts used for this purpose were supplied by the Extended Forecast Division of the U. S. Weather Bureau and are given in figure 16. These charts comprise normals for whole months and mid-month to mid-month periods based on 16 years of data. Dates applied to the individual charts are as follows:

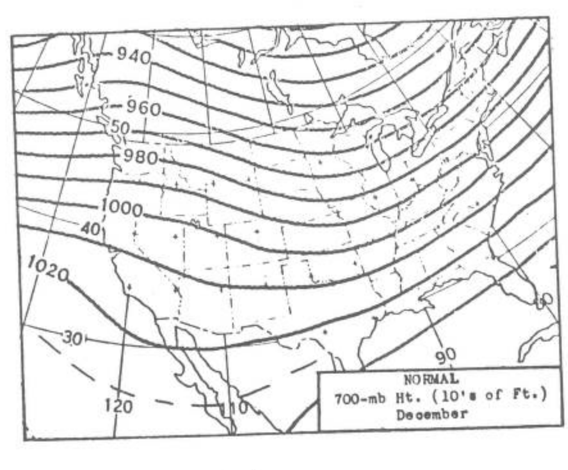
Inclusive Dates	Chart	Period
Nov. 23 - Dec. 7	(a)	Nov. - Dec.
Dec. 8 - Dec. 22	(b)	Dec.
Dec. 23 - Jan. 7	(c)	Dec. - Jan.
Jan. 8 - Jan. 22	(d)	Jan.
Jan. 23 - Feb. 7	(e)	Jan. - Feb.
Feb. 8 - Feb. 22	(f)	Feb.
Feb. 23 - Mar. 7	(g)	Feb. - Mar.

From this table, the position of the 700-mb. Low is located on the appropriate normal chart for the given date, and the normal height at this point is read off in 10's of feet. Since operational charts are analysed in meters (geopotential), the normal height read in feet must be converted to meters. A nomogram is given in figure 17 to aid in this step. The difference in the observed and normal heights (observed minus normal) in meters gives the departure from normal (DN) values which are then used to classify the individual situations according to the following class intervals:

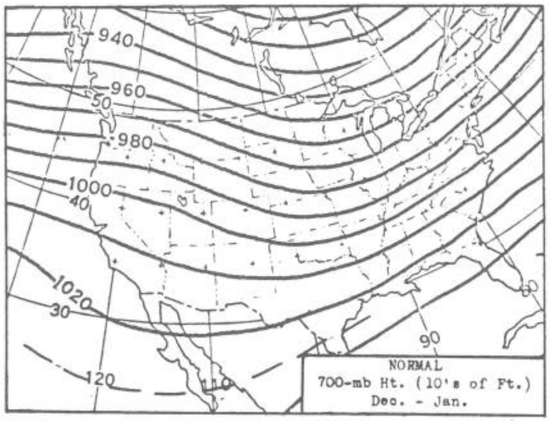
Class I	$DN \geqslant -30$ (meters)	(DN equal to or more positive than -30 m.)
Class II	$-30 > DN > -125$	(DN between -30 and -125 m.)
Class III	$DN \leqslant -125$	(DN equal to or more negative than -125 m.)



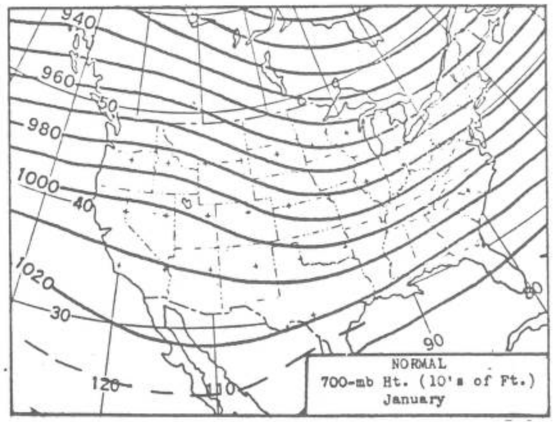
(a)



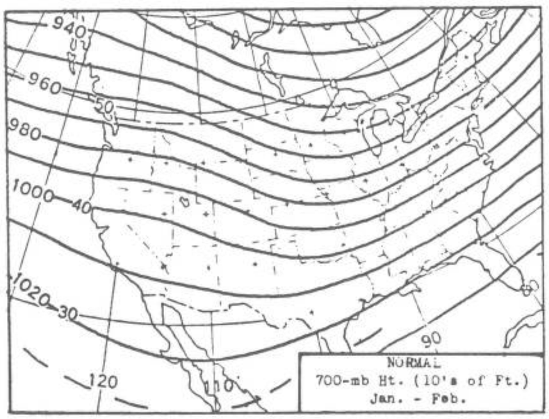
(b)



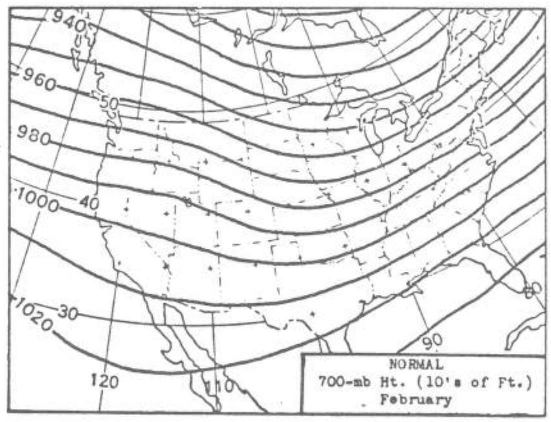
(c)



(d)

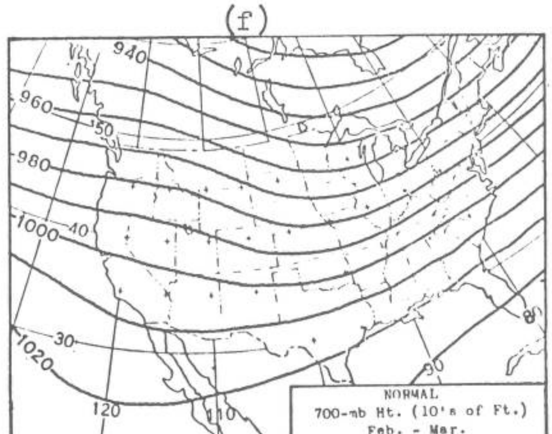


(e)



(f)

Figure 16. - Harmonically smoothed 700-mb. normal charts (B. M. Lewis, "Normal 700-mb. Height and Sea-Level Pressure Obtained by Harmonic Smoothing of Observed Data," Extended Forecast Division, Unpublished manuscript, Aug. 1964, 5 pp.)



(g)

700 mb HEIGHT

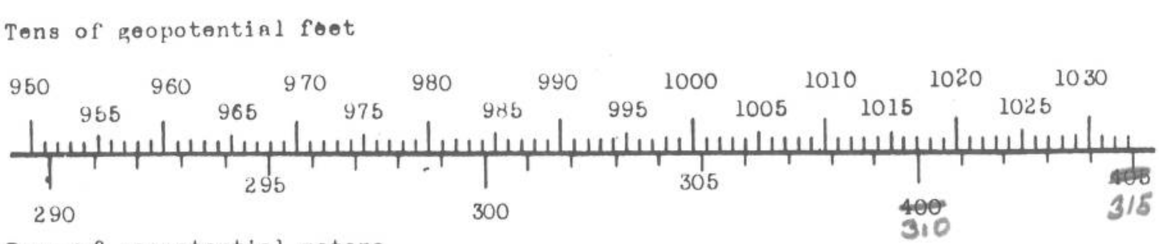


Figure 17. - Nomogram for converting 700-mb. heights read from normal charts into meters for comparison with values read from operational charts.

APPENDIX B

MATHEMATICAL DEVELOPMENT USED IN COMPUTER PROGRAM

The mathematical relationships used in the computer program are given by Jorgensen [3]. Since the grid system coincides with the surface of the earth, with the grid lines made up of great circles, the most effective programing procedure was through the use of spherical trigonometric relationships. A diagram showing the spherical triangles involved is given in figure 18.

The solution to the following problem is required of the computer:

Problem

Given: (a) Latitude and longitude of center of upper Low at point A (see fig. 18). (b) Latitude and longitude of station reporting precipitation at point B. (c) Amount grid rotated in degrees (counter-clockwise).

To find: The ordinate and abscissa (a' and b', respectively) of point B in grid network.

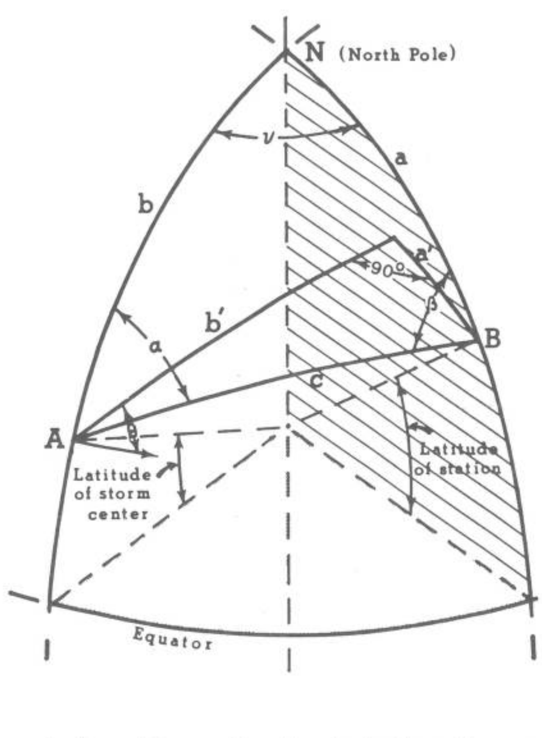


Figure 18. - Diagram giving the spherical triangles used in developing the machine program. Upper low center is at point A with reporting station at point B. Grid may be rotated about point A by an amount Θ.

Solution

(a) The arc distances a, b, and c may be regarded as sides of a spherical triangle in which the vertex opposite each of these arcs is at the center of the earth. Therefore, the arc distances (in units of degrees latitude) and the angles subtended by the bounding earth's radii are numerically equal.

(b) Arc distance $a = 90° -$ latitude of B
$b = 90° -$ latitude of A

Angle ν = difference in longitude between points A and B (longitude of point A minus longitude of point B). We have therefore two sides and the included angle of triangle ABN on the surface of the earth. Angle α can then be determined by solving simultaneously the two following equations:

$$\tan\frac{1}{2}(\beta - \alpha) = \frac{\sin\frac{1}{2}(b - a)}{\sin\frac{1}{2}(b + a)}\cot\frac{1}{2}\nu \qquad (1)$$

$$\tan\frac{1}{2}(\beta + \alpha) = \frac{\cos\frac{1}{2}(b - a)}{\cos\frac{1}{2}(b + a)}\cot\frac{1}{2}\nu \qquad (2)$$

(c) From angle α, the arc distance c (in degrees of latitude) can be determined from the relationship:

$$c = \sin^{-1}\frac{\sin\nu \sin a}{\sin\alpha} \qquad (3)$$

(d) Having found angle α and arc distance c, and knowing θ, one can determine the coordinates a' and b' from the following relationships:

$$a' = \sin^{-1}[\sin c \sin(90° - \alpha - \theta)] \qquad (4)$$

$$b' = \tan^{-1}[\tan c \cos(90° - \alpha - \theta)] \qquad (5)$$

APPENDIX C

DATA AMOUNTS USED IN ANALYSES

During the period covered by the investigation, 645 predominant upper Lows were tabulated as occurring in the specified area. For each of these Lows, the precipitation amounts reported by the station network were examined by computer to determine, in effect, whether a "precipitation case" had occurred in each 1° by 1° latitude cell of the grid network, with the upper Low located at the origin of the grid. A precipitation case consisted of one or more stations reporting precipitation within the boundaries of the cell, the amount credited to the cell being made up of the average of all stations reporting within it. Whenever a part of the grid system fell outside the station network—this was a common occurrence—it became impossible for this portion of the grid to have precipitation cases allocated to it. The total number of cases recorded per cell can be expected to be related to the number of observation periods the cell is over the observing area and also to the density of the observing network. As a consequence, the total number of cases tabulated per cell is not uniform over the grid system.

The number of cases per cell recorded for all 645 upper Low situations is given in the form of an analysis of the relevant data in figure 19, part (a). The number of cases per cell ranged from 23 in the extreme southeastern corner of the grid to a high of 280 about 6° latitude to the north-northwest of the Low center, with the average number of cases per cell amounting to 124.

The grouping of the tabulated upper Lows into three classes according to their DN values gives the distribution of cases over the grid network shown in the remaining charts of figure 19. In Class I (fig. 19b), the number of cases per cell ranged from 3 in the southeastern corner of the grid to 87 about 7° north of the center, with an average number per cell of 31. The number of precipitation cases in Class II (fig. 19c) ranged from 7 to 150 per cell, with an average number of 60, while for Class III (fig. 19d) the number ranged from 8 to 68, with an average number of 34.

Data in Classes II and III were broken down further into several precipitation intensity classes, thus reducing the number of cases on which the analyses in figures 10 through 15 are based. However, the frequencies of the individual intensity classes (expressed as percentages) must add up to the frequencies for all cases, e. g., figures 13, 14, and 15 must add up to figure 9. This fact, together with considerable smoothing, is believed to have given analyses of the precipitation intensity patterns which are of worthwhile accuracy.

Considerable smoothing was necessary in carrying out the analyses given in the figures resulting from this investigation. This smoothing was performed subjectively with regard to the overall pattern of the individual chart.

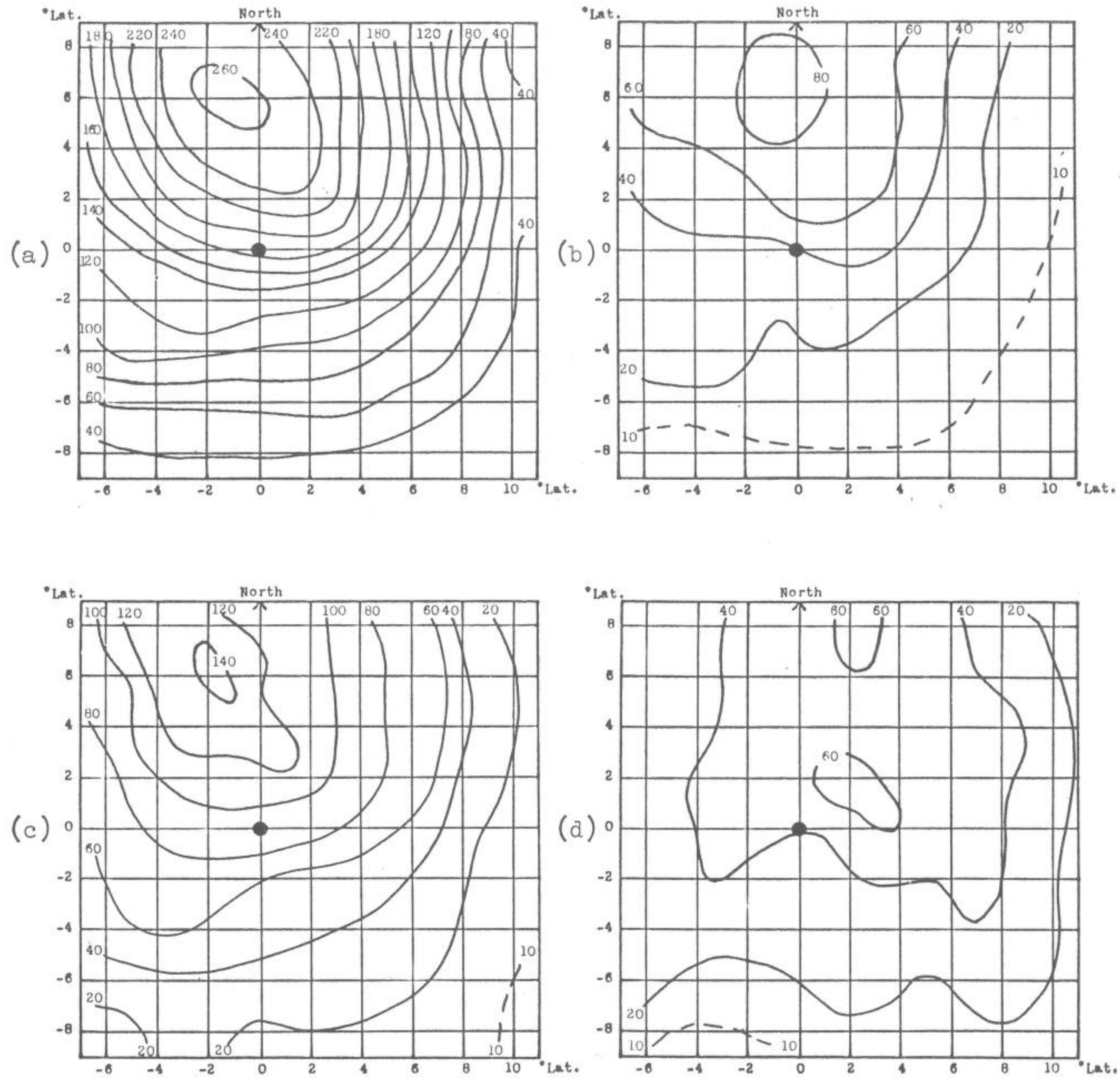


Figure 19. - Analyses showing the number of precipitation cases per cell. (a) for all 645 upper Lows combined, (b) for the 180 Lows of Class I, (c) for the 314 Lows of Class II, and (d) for the 151 Lows of Class III.

APPENDIX D

BASIC ASSUMPTIONS

In carrying out an investigation of this nature, certain basic assumptions are made regarding the physical background of the problem and the data employed. Some of these assumptions have been expressed, and others implied. Several assumptions made in planning this study, which may require additional discussion, are treated in the following sections:

(1) Space and Time Stability. - In investigating weather phenomena over such a varied topographical area as the intermountain region, the stability of the results in terms of space and time is likely to be less than desired. This is especially true concerning space stability when using a moving grid system such as was employed in this investigation. However, in expressing precipitation amounts in terms of percentages of station normals, space variability has been considerably reduced. It can be seen that a storm moving over an area, which deposits the same percentage of station normal at each station, would completely eliminate the variability of the normal precipitation pattern shown in fig. 1 over the intermountain region, leaving only the anomalies of the individual storm system. Planned studies of individual stations will reduce the importance of this aspect of the problem.

The assumption of time stability is also serious in that there is little that can be done to reduce the importance of the problem. It is commonly observed that the weather in the arid western regions, and elsewhere, may show significant trends away from the normal for periods lasting several years or more. These anomalous periods will affect the normals which include them, which in turn could affect adversely the output of this study. Longer periods used in computing the normals would tend to reduce the importance of this effect. There is no evidence to indicate that the effectiveness in producing precipitation of cyclonic circulation aloft would vary with time.

(2) Data and Data Treatment. - In order to avoid a subjective re-evaluation of each 700-mb. Low, the indicated position of each Low on the manuscript charts was taken at face value. For intense systems, the location of the center of circulation was in little doubt. For weak and diffuse systems the exact center was much more in question. However, a mitigating factor here is that little or no precipitation resulted from the weak systems, and, consequently, their exact position was of less significance.

The choice of a 7-day period for expressing station normals was based on several factors. Although precipitation amounts broken down into 7-day periods were not available for this investigation, normal charts are in existence based on 7-day periods. Thus, if a significant trend in normal precipitation amounts was evident during the four weeks of a month, the results of the study could be adjusted to take this trend into account.

In addition, since precipitation amounts were to be expressed in percentages, normal values were desired for which a 1 to 5 percent quantity would closely represent the smallest measurable amount, namely, .01 inch. This requirement was closely approximated when the 7-day normal was used for the western area.

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