CUTOFF LOWS IN THE SOUTHWESTERN UNITED STATES AND THEIR EFFECTS ON THE PRECIPITATION OF THIS REGION

A Study of Circulation Features that may be Recorded by Tree Rings

by Arthur V. Douglas

Final Report

June, 1974

on project entitled

Dendroclimatic History of the United States

Department of Commerce

Contract 1-35241-No. 3

Harold C. Fritts, Principal Investigator

Laboratory of Tree-Ring Research

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Environmental Data Service
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INTRODUCTION

The frequency of occurrence of mean upper-level troughs and ridges in western North America is primarily dependent upon orographic influences, ocean-continent boundaries, and seasonal changes in heat within the ocean and across the continent. In addition, Namias (1968) has indicated that large-scale changes in sea surface temperatures throughout the North Pacific can affect upper-level ridging or troughing in the western United States. The seasonal circulation patterns of this region are not, however, always influenced by these factors in the same degree or manner.

Throughout most of the year the western United States is under the influence of the circumpolar vortex, with extratropical cyclones and attendant fronts commonly approaching the coast between Alaska and California. The eastward movement of these storms is highly affected by the mountain ranges of western North America.

As the circumpolar vortex expands southward in the fall, the annual peak in precipitation is also observed to migrate southward along the west coast of North America. In southern Alaska October is the wettest month, while in Baja California del Norte, January is the wettest month (Pyke, 1972). In winter, however, droughts can occur in western California and Baja California when upper-level ridging becomes prominent along the west coast with a resultant displacement of storms into Canada and Washington north of their normal track.

During the end of June, the subtropical jet stream across the southwestern United States begins to dissipate as a result of seasonal warming throughout the Northern Hemisphere. Subsequently an upper-level high builds northwestward from the Gulf of Mexico into the western United States. This dynamically forced upper-level pressure pattern results in a flow of fairly warm, moist, and unstable air into the region east of the coast ranges and south of central Nevada and central Utah (Pyke, 1972). In Arizona the arrival of this moisture has been termed the "summer monsoon" (Bryson and Lowry, 1955). In some years, however, the summer monsoon fails to become well-established. One cause for deficient summer rains in the Southwest is commonly the failure of the upper-level circulation to maintain a steady flow of moisture from the Gulf of Mexico. In these cases drier, cooler, and fairly stable air is observed to flow across the region from the southwest (Douglas and Fritts, 1973). This upper-level anomaly is associated with a southward displacement of the upper-level westerlies and a resultant retreat of the upper-level anticyclone toward the southeast. In other summers, however, drought occurs when the upper-level anticyclone becomes cut off from the main upper-level ridge located across the southeastern United States. With a single high pressure cell over northern Arizona, there is a net transport of relatively cool dry air southward on the east side of the anticyclone. In this situation drought conditions may prevail across eastern Arizona, New Mexico, and northwest Texas.

Near the end of August sea surface temperature (SST) along the southwest coast of Baja California can become warm enough ($\geq 27^{\circ}$ C) to allow the movement of tropical storms close to the Southwest (Douglas, 1972). These tropical storms or dissipating tropical depressions may cross the region in August, September, or October causing heavy precipitation. During some falls, however, cool SST off Baja California or strong upper-level westerlies are believed to preclude the movement of these storms into the Southwest. By late October or early November, the circumpolar vortex has expanded far southward, bringing a chance for precipitation in the Southwest from extratropical storms (Pyke, 1972).

PURPOSE

Upper-level troughing or ridging over the eastern North Pacific and along the west coast of North America is favored during the spring and fall when the circumpolar vortex is thermally forced to adjust to a new state (contraction in the spring, expansion in the fall) (Sands, 1966). Under these periods of circumpolar vortex adjustment, upper-level cutoff lows are commonly observed to form along the west coast of North America. Simpson (1952) has noted that in the drought-subject areas of Hawaii, more than half the annual rainfall occurs from two or three storms, known as Kona storms. These winter storms develop from upper-level cold cyclones which are commonly observed at the 500 mb level. Simpson states that "in the subtropical eastern Pacific, the development and movement of cold lows in the upper-troposphere constitute one of the important features of the circulation." In western North America these cutoff cyclones frequently develop when an upper-level trough enters the west coast and the southern sector of the trough becomes sheared off from the main stream of the circumpolar vortex. With highest frequency of occurrence in May, June, September, October, and November, these cutoff lows are important sources of cloudiness and precipitation during the normal drought periods of fall and spring in the southwestern United States.

The purpose of this report is to analyze the possible influence of these cold upper lows on the seasonal precipitation regimes of the arid southwestern portion of the United States. The occurrences of these upper-level disturbances are generally a small but important part of broad scale patterns in the atmospheric circulation. However, in order to assess their importance climatologically, it is necessary to obtain a record of their temporal and spatial occurrence.

This analysis will complement the earlier work on tropical storms by Douglas (1972) and temperate lows by Blasing (submitted). These studies provided some of the background necessary to understand the long-term states of past climate as reconstructed by analysis of tree rings.

PROCEDURE

Atkinson (1971) believes that studies of Kona storms by Simpson (1952) and Ramage (1961) appear to show conflicting results due to varying classifications of Kona storms. Atkinson attributes this conflict to the inclusion of deep polar troughs rather than cutoff lows in Simpson's data. Palmén and Newton (1969) have presented a classification of major types of cold troughs and cutoff cyclones. Of particular interest to our study is their type of cutoff low which is characterized by an almost circular vortex which is located south of a newly-formed jet stream (Palmén and Newton type _d_ cutoff). This type _d_ cutoff low is thus the "idealized" Kona storm described by Simpson and Ramage. The particular criteria for the classification of upper-level lows used here were developed to eliminate the problem of including deep polar troughs with closed central isobars. These deep troughs commonly are associated with a split polar jet--one branch to the north of the low center and the other branch associated with the western, southern, and eastern quadrants of the low center. Attention was thus restricted to circular vortices south of the polar jet.

All 500 mb lows from Historical Weather Maps (1945-1960) and Daily Weather Maps (1961-1972) (U. S. Weather Bureau, Air Weather Service, ESSA, and NOAA 1943 *et seq.*) were examined. Type *d*, upper-level lows selected for this study met the following criteria:

a. Location between 25°-45° N and 105°-145° W.

b. Lows with at least two closed isobars, representing a 200 foot lowering of the 500 mb height level.

c. Central temperatures $\geq -25^{\circ}C$.

d. Association of the cutoff low with a migratory upper-level "parent anticyclone," with the 500 mb level of the high no greater than 500 feet above the outer fringes of the low.

e. Persistence of the low within the region for at least two days.

The requirement *b.* was chosen because Korte, Jorgensen, and Klein (1969) have noted that 500 mb lows produce little precipitation in the western United States until the lows become fairly intense. Cyclones meeting the above criterion *b.* are of approximately the same intensity as the more frequent rain-producing Class II and Class III lows of Korte *et al.* (1969). Korte's Class II lows have central heights from 60 m to 240 m below the normal monthly 500 mb level heights, and

Class III lows have central heights less than 240 m below the normal monthly 500 mb heights. The simple criterion of two or more closed isobars allowed tabulation of all cold upper cyclones in considerably less time than would be possible in the Korte system which uses central pressure departures from normal. In addition, it was felt that an evaluation of rainfall from lows would be more clear-cut if only intense cutoff cyclones were studied. Those cold upper lows with weak pressure gradients are generally hard to assess in terms of their rain producing effects, as localized showers need not be a direct result of the cold cutoff low, but rather precipitation can be due to residual moisture combined with local orographic influences. Little doubt as to the source of precipitation is encountered when studying the more intense Class II and Class III storms.

Criteria b., c., and d. were established to insure the probability that the cutoff low was south of the main stream of the upper-level westerlies. These criteria also permitted a quicker review of all lows indicated on Historical and Daily Weather maps from 1945-1973.

OCCURRENCE OF CUTOFF LOWS AND CIRCULATION PATTERNS

During the period 1945-1973, 64 cutoff lows were detected within the study area; their monthly occurrence is given in Table 1. It should be noted from this table that these cyclones occur most frequently during two periods--in May and June, and again from September through November. The total number of cutoff lows per year is given in Figure 1. This figure and Table 1 illustrate the fact that in most years cold cutoff lows are more frequent in the last half of the year rather than in the first half, (e.g. 1949, 1955, 1958).

Table 1. Frequency of cutoff lows in the study region by month for the period 1945-1972.

	J	F	M	A	M	J	J	A	S	O	N	D	Total
1945						1							1
1946													0
1947													0
1948					1	1				1			3
1949	1				2	1			1				5
1950									1				1
1951													0
1952						2							2
1953				1					2				3
1954										1	1		2
1955					2	1							3
1956										1			1
1957					1				2	1			4
1958		1			1	1			1				4
1959											1		1
1960										1	1		2
1961					1						1		2
1962													0
1963	1					1				1			3
1964									1		1		2
1965	1					1							2
1966			1		1		1	1	2	1			7
1967					1	1			1		1		4
1968									1	1			2
1969						1				1	1	1	4
1970													0
1971							1	1					2
1972										2			2
1973									2				2
Σ	3	1	1	1	10	11	2	2	14	11	7	1	64
Average	.2	*	*	*	.5	.6	.1	.1	.7	.6	.4	*	3.2

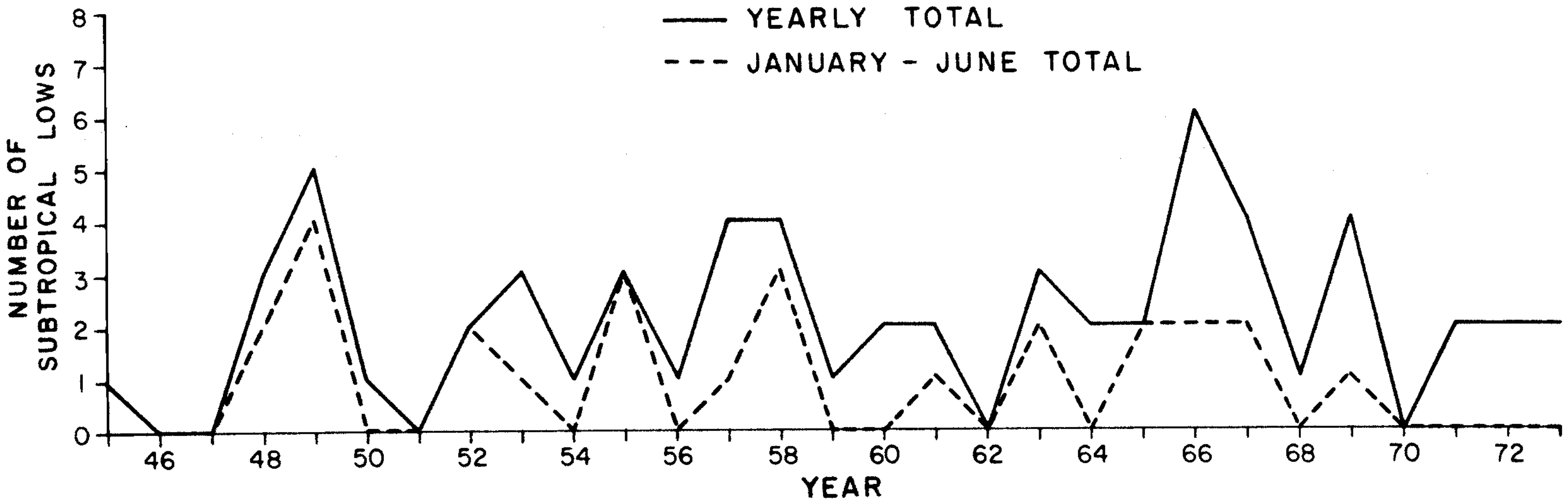

Figure 1. The yearly occurrence of cold upper lows in southwestern North America and offshore regions during the period 1945-1972. Solid line indicates total number of lows for the entire year while dashed line represents the total number of storms occurring during the sub-period January through June.

Figures 2, 3, and 4 show the approximate locations of all cutoff lows by month of occurrence. The majority of these cold cutoff cyclones formed on the southern edge of an upper-level trough, which had entered the northwestern United States a few days prior to the formation of the upper low. Deepening of the cold cutoff cyclone usually did not occur until the initial low center had passed south of 40° N and west of 110° W.

As noted earlier, upper-level cold lows are most frequent when the circumpolar vortex is undergoing readjustment, and troughing and ridging become prominent along the west coast of North America (Sands, 1966). In order to better document conditions leading to the formation of these storms with respect to large-scale atmospheric patterns of troughing and ridging, it was decided to present the teleconnection charts of O'Connor (1969). These charts (Figures 5 and 6) portray calculations of O'Connor which express the probability of sign (positive or negative) of 700 mb height anomalies over North America accompanying all cases of negative height anomalies in the spring and fall centered at selected 10 degree squares. Since few cutoff lows have occurred in winter and summer (Table 1) only the maps for spring and fall are presented here. The upper-level anomaly patterns associated with the occurrence of all low pressure anomalies within the study region, indicate the tendency of all lows to be associated with an upper-level ridge of high pressure to the west or north of the low pressure anomaly. This high is the "parent anti-cyclone" described by Simpson. In part, the air flow on the east side of this high initiates the splitting off of the southern half

Figure 2.

The location by month of each type *d* cutoff low in the study region for January, February, March, and April (1945-1972). Data tabulated from 500 mb charts on Historical Weather Maps and Daily Weather Maps.

Figure 3.

The location by month of each type *d* cutoff low in the study region for May, June, July, and August (1945-1972). Data tabulated from 500 mb charts on Historical Weather Maps and Daily Weather Maps.

Figure 4.

The location by month of each type *d* cutoff low in the study region for September, October, November, and December (1945-1972). Data tabulated from 500 mb charts on Historical Weather Maps and Daily Weather Maps.

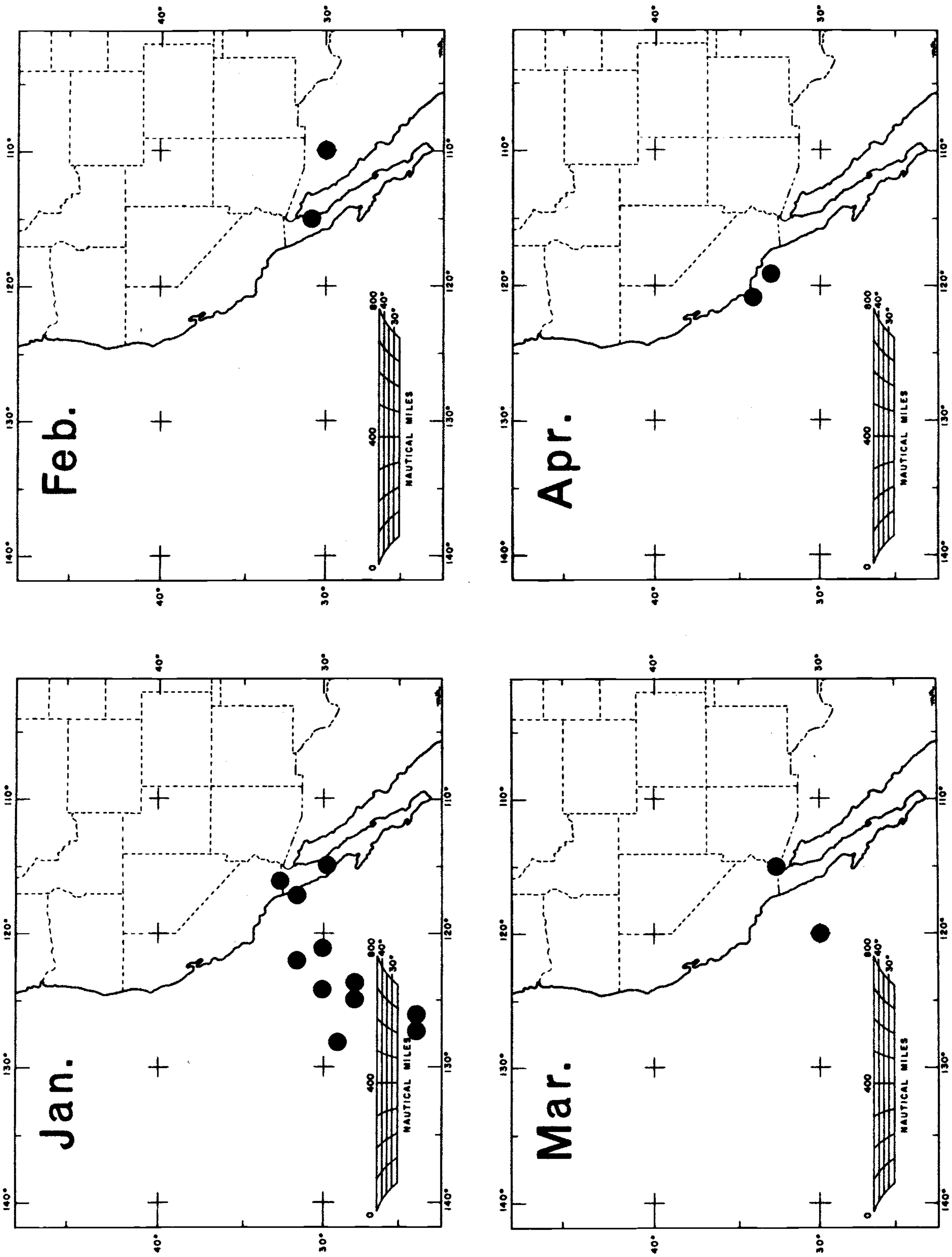
Jan.
Feb.
Mar.
Apr.
110°
120°
130°
140°
40°
30°
0
400
800
40°
30°
NAUTICAL MILES

Figure 2.

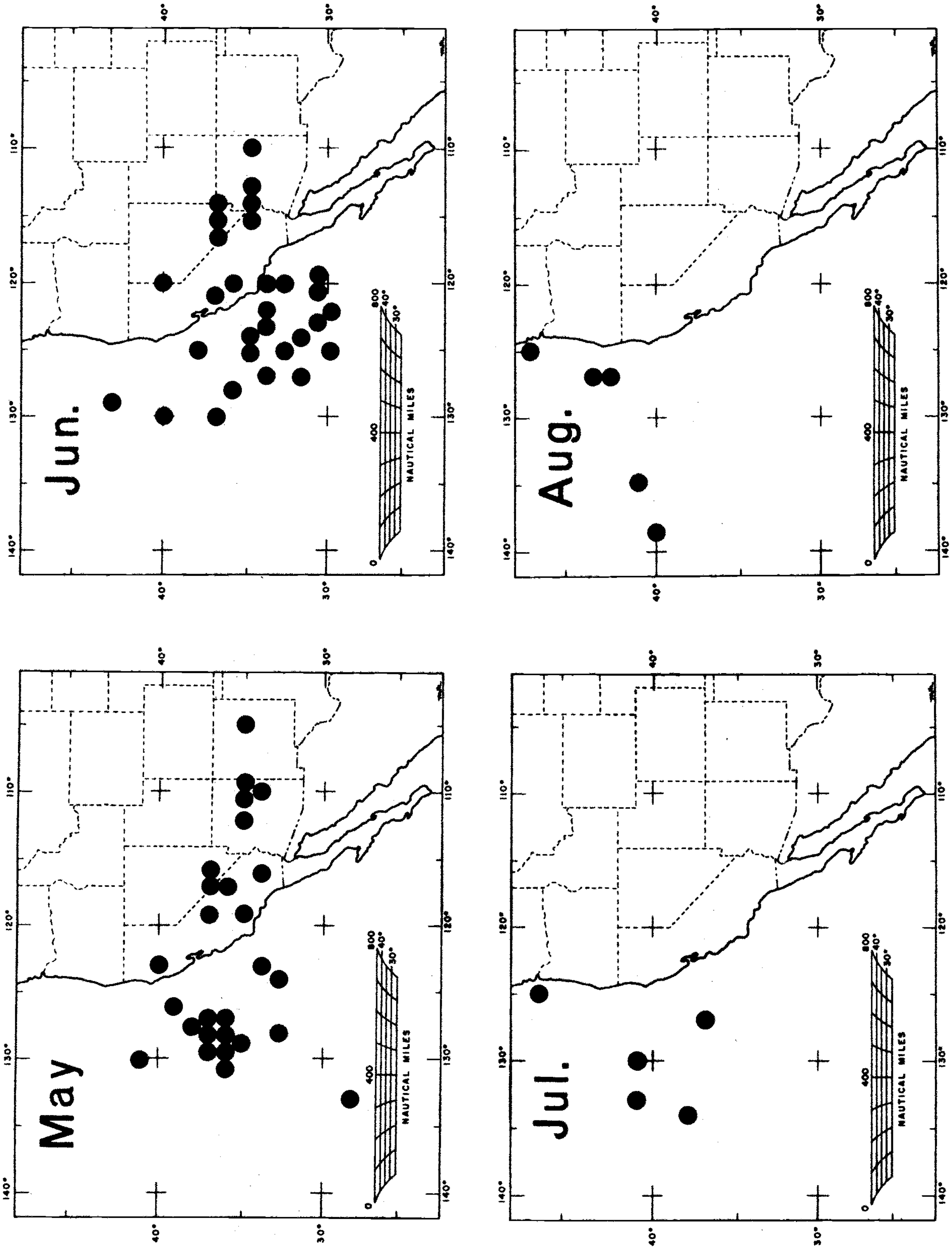

Figure 3.

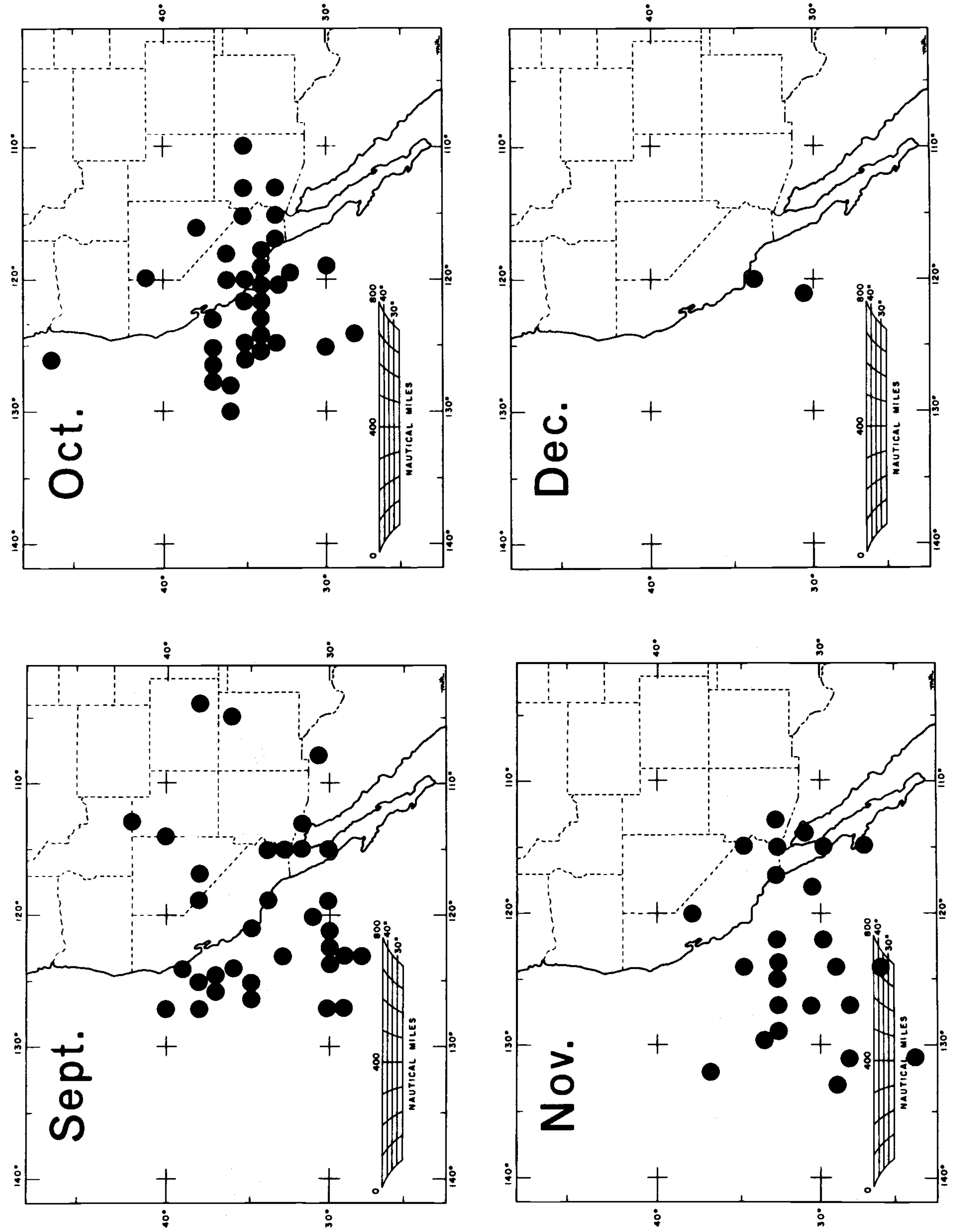

Figure 4.

Figure 5.

Spring 700 mb teleconnection maps from O'Connor. The contoured values are the sign and the probability of a given pressure occurring at each gridpoint, given the occurrence of a negative anomaly. Specified locations indicated by the value -100 at the given latitudes and longitudes.

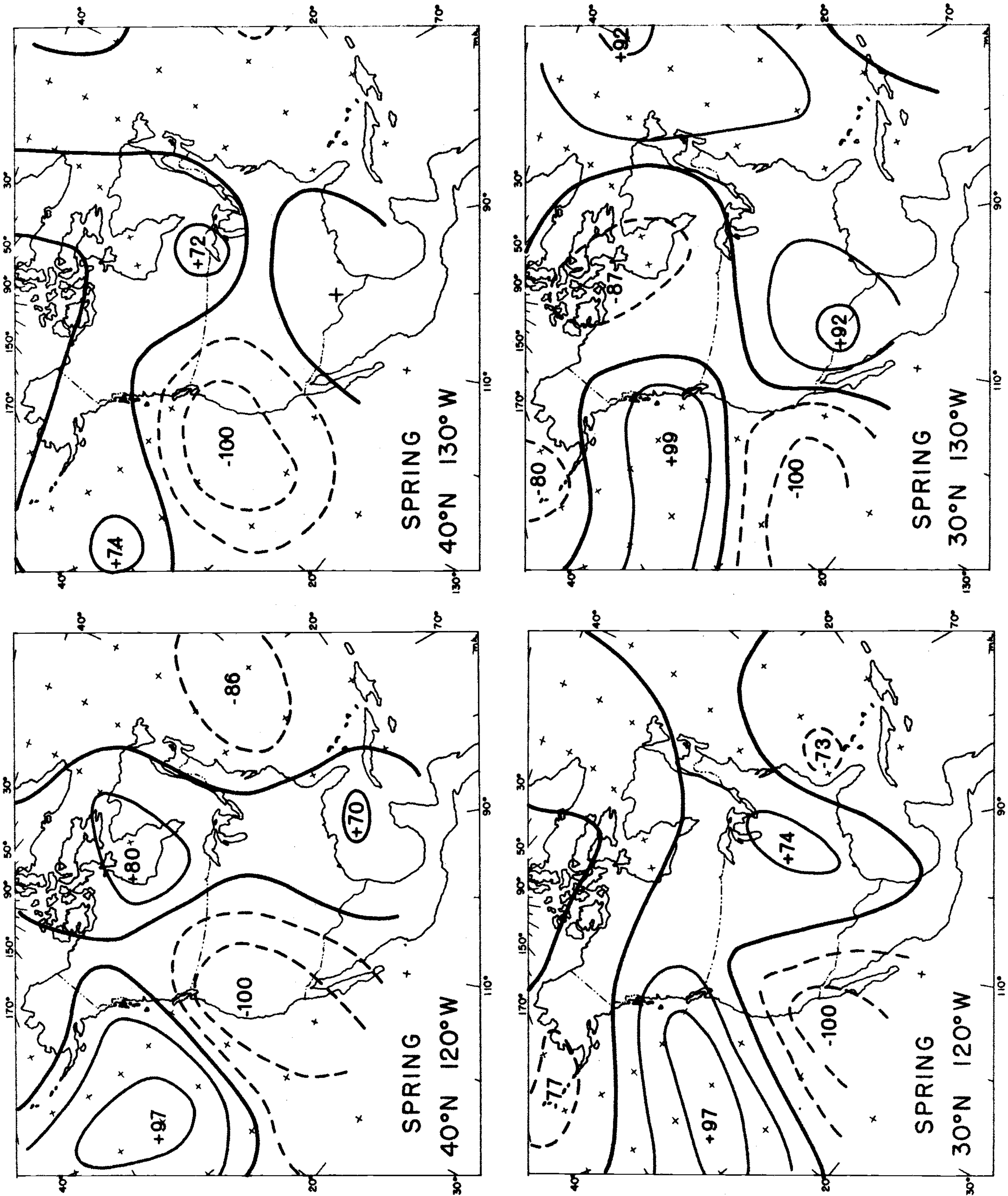
SPRING 40°N 130°W
+74
-100
+72
SPRING 30°N 130°W
-80
+99
-100
-87
+92
+92
SPRING 40°N 120°W
+97
-100
+80
+70
-86
SPRING 30°N 120°W
-77
+97
-100
+74
-73
40°
20°
130°
70°
30°
50°
90°
150°
170°
110°

Figure 5.

Figure 6.

Fall 700 mb teleconnection maps from O'Connor. The contoured values are the sign and the probability of a given pressure occurring at each gridpoint, given the occurrence of a negative anomaly. Specified locations indicated by the value -100 at the given latitudes and longitudes.

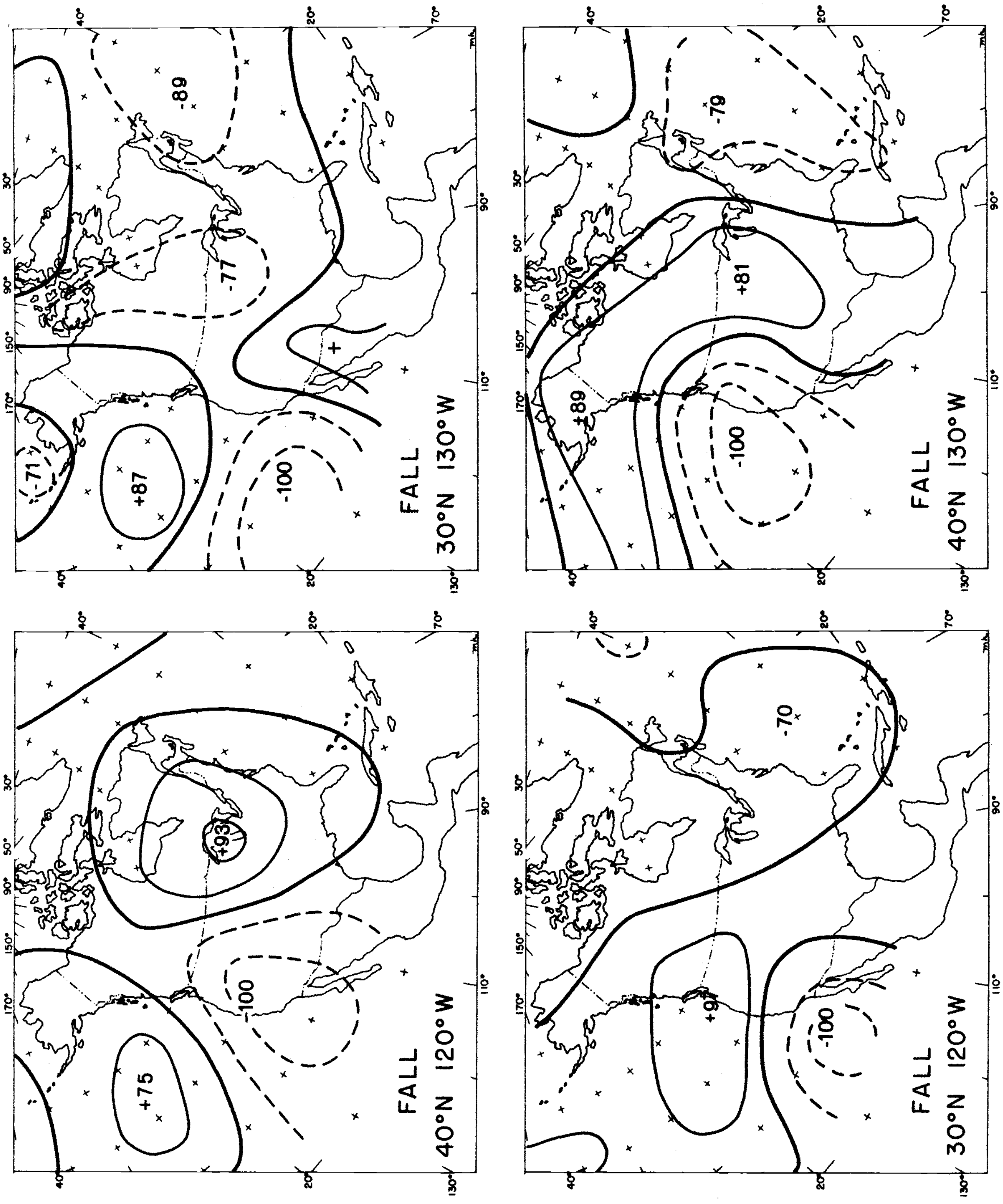
FALL
30°N 130°W
-89
-77
-71
+87
-100
FALL
40°N 130°W
-79
+81
+89
-100
FALL
40°N 120°W
+93
+75
-100
FALL
30°N 120°W
-70
+91
-100
40°
30°
50°
90°
150°
170°
20°
70°
90°
110°
130°

Figure 6.

of the trough, with resultant cutoff low formation and subsequent southward movement of the developing cutoff low. It was noted that in almost all cases that were tabulated, the cold cutoff lows did not form until the parent anticyclone had moved to the northwest of the low center--a condition favored by the upper atmosphere of the eastern North Pacific as indicated in some of the teleconnection maps. Once the cutoff low had formed, the associated upper-level trough either filled or continued to move eastward into the eastern Rockies or the western plains. By the time the cyclone had become totally cut off from the eastward moving trough, the polar jet entering the North American continent was well north of 45° N. With a high latitude position of the polar jet, there was little or no influence exerted by the jet upon the cold cutoff low and its subsequent movements.

MOVEMENT OF COLD CUTOFF LOWS AND STORM FREQUENCY

Cold cutoff lows are characterized as having very erratic movements during their lifetime. Upon breaking off from the westerlies, the lows often drift southwards and occasionally westwards. Since the cyclones of primary interest in this report are always south of a newly formed polar jet (Palmén and Newton type d), the final stage of the cold upper low occurs when it reenters the westerlies. Until then, however, their movement is often controlled by the upper-level circulation around the warm ridges or cutoff anticyclones surrounding the low center. Depending upon its location with respect to nearby anticyclones or ridges, a low may move in any direction in its lifetime. The erratic movement of cold upper lows across the Southwest is a result of the interplay between the circulations of the upper-level highs east and west of the cold upper cyclones.

The percentage frequency of direction of movement of all types of cutoff lows throughout the year, computed for 10° squares, is given in the upper left portion of Figure 7. North of 40° N, most cold upper cyclones travel in an easterly to southerly direction. Off the California coast a southeasterly direction of movement is most common throughout the year. Upon entering the southwestern United States, those cold upper cyclones at latitudes south of 40° tend to move in a northeast to southeast direction.

Seasonal analyses of cutoff lows are given in Figure 7. During May and June these types of cyclones are most frequent between 30° N and 40° N and 110° W to 130° W. Off the California coast a southeast movement of these cutoff lows is most common (Figure 7). Upon passing over the continent, the storms tend to move eastward or southeastward. Typically these types of cyclones merge with an upper-level trough prior to their passage across the plains.

Cutoff lows show less persistence in their direction of movement during September, October, and November (Figure 7). Unlike spring cutoff lows, those of fall show a frequent tendency to move offshore in a southerly to westerly direction. Intensification of cold upper cyclones is common with a movement of the low center offshore and toward the south. This condition of intensification and increased moisture content will be discussed later in the paper.

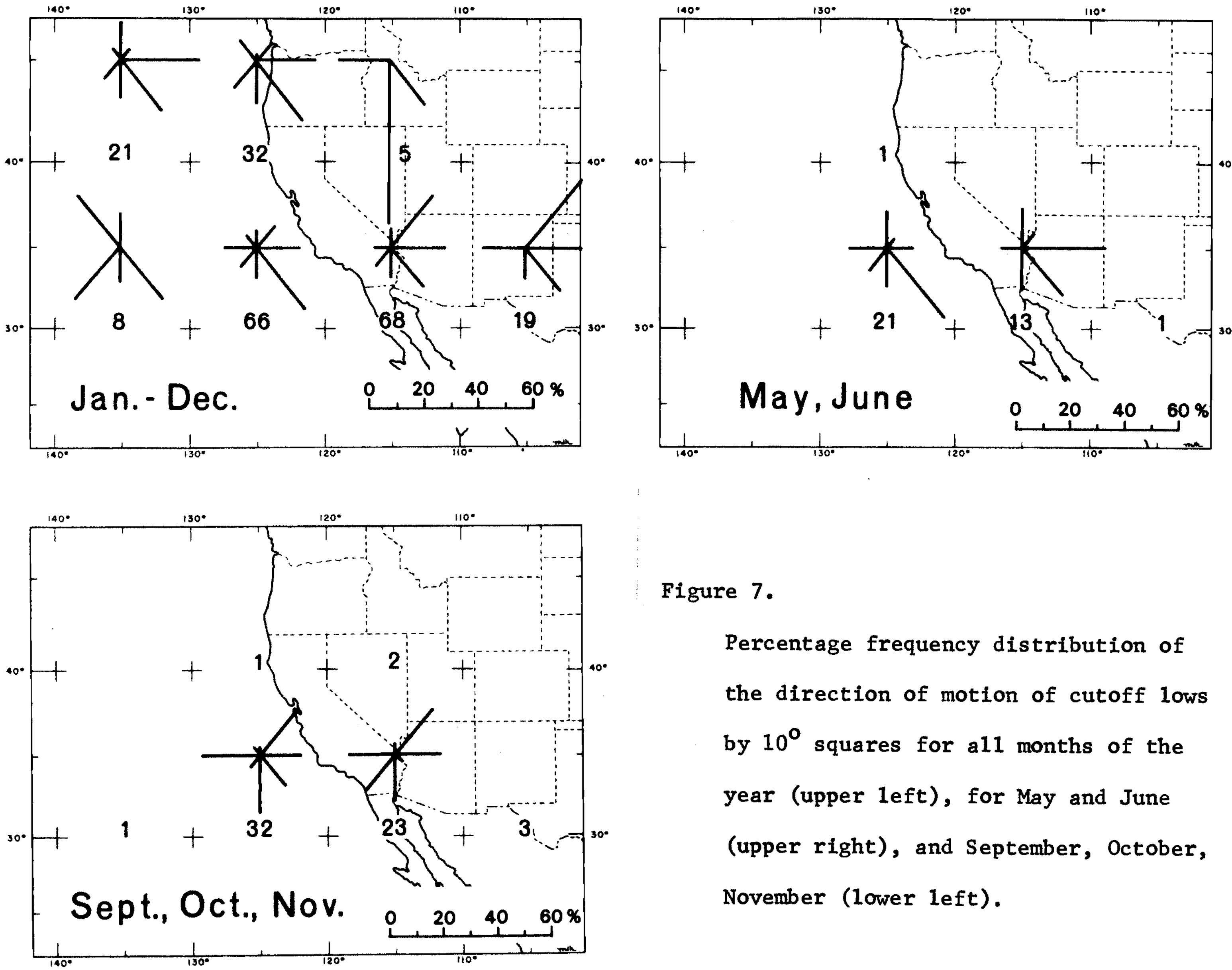

Figure 7.

Percentage frequency distribution of the direction of motion of cutoff lows by 10^{o} squares for all months of the year (upper left), for May and June (upper right), and September, October, November (lower left).

Figure 7.

The frequency of cutoff lows varies considerably from year to year. With the advent of satellite coverage of these storms beginning in 1966, the number of detected cold upper lows has averaged three per year (Table 1). However, yearly totals have ranged from seven in 1966 to none in 1970.

An examination of Table 1 and Figures 2, 3, and 4 reveals a double maximum in cutoff low frequency. On the average, one cold upper cyclone forms in May or June. A lull in cutoff low formation occurs in the summer, while in the fall one or two lows may be expected. From December through April, cutoff cyclones are very infrequent with an average of one storm about every three or four years.

CUTOFF LOW PRECIPITATION IN THE SOUTHWEST

In an earlier report Douglas and Fritts (1973) analyzed the importance of tropical storm precipitation in the Southwest. As a follow-up to that investigation, this section will consider the precipitation associated with cutoff lows.

As noted in the earlier report, it is often difficult to determine the exact source of precipitation in the Southwest due to a broad area of inadequate meteorological data in Mexico and across the eastern North Pacific. With the advent of full coverage satellite data in 1966, however, it became possible to more adequately trace the sources of precipitation in the southwestern United States. Analyzing daily satellite data from July 1967 to September 1971, the following characteristics of the ten recorded cutoff lows (Table 1) were observed:

1) Cloudiness arranged in spiral bands.

2) Greatest cloudiness and precipitation in the eastern quadrants regardless of the movement of the storm.

3) Tendency of the Intertropical Convergence Zone (ITCZ) to bulge northwards in response to the upper-level cyclonic circulation.

Characteristics 1. and 2. are to be expected according to data presented by Simpson (1952) and Palmén and Newton (1969). All three authors emphasize the tendency of cutoff lows in the subtropics to show an asymmetric distribution of precipitation around the center of the cyclone with heaviest precipitation in the eastern quadrants. The apparent interaction of the cutoff lows with the ITCZ (characteristic 3.) has not been discussed by these earlier researchers, and thus is discussed more fully in the following section.

CASE STUDY NOVEMBER 9-15, 1969

In our study we were fortunate to be able to critically analyze satellite and upper-level data on the particularly severe cyclone of November 9-15, 1969 (Figures 8 and 9). This cyclone developed in the southwest section of a rapidly eastward moving trough. On November 8 no spiral cloud configuration was evident from the satellite data. By the 9th, however, a fairly strong circulation had developed (Figure 8). The low had migrated offshore so that it was off northern Baja California. Particularly heavy precipitation occurred during November 9 through 12 across the southwestern United States. The precipitation occurred in a southerly flow of moist tropical air onto the continent (Figures 8 and 10).

Figure 8.

Distribution of major cloud clusters (redrawn from actual ESSA satellite photographs) in the eastern North Pacific, and 12Z, 500 mb charts for the same days of November 9 and 11, 1969.

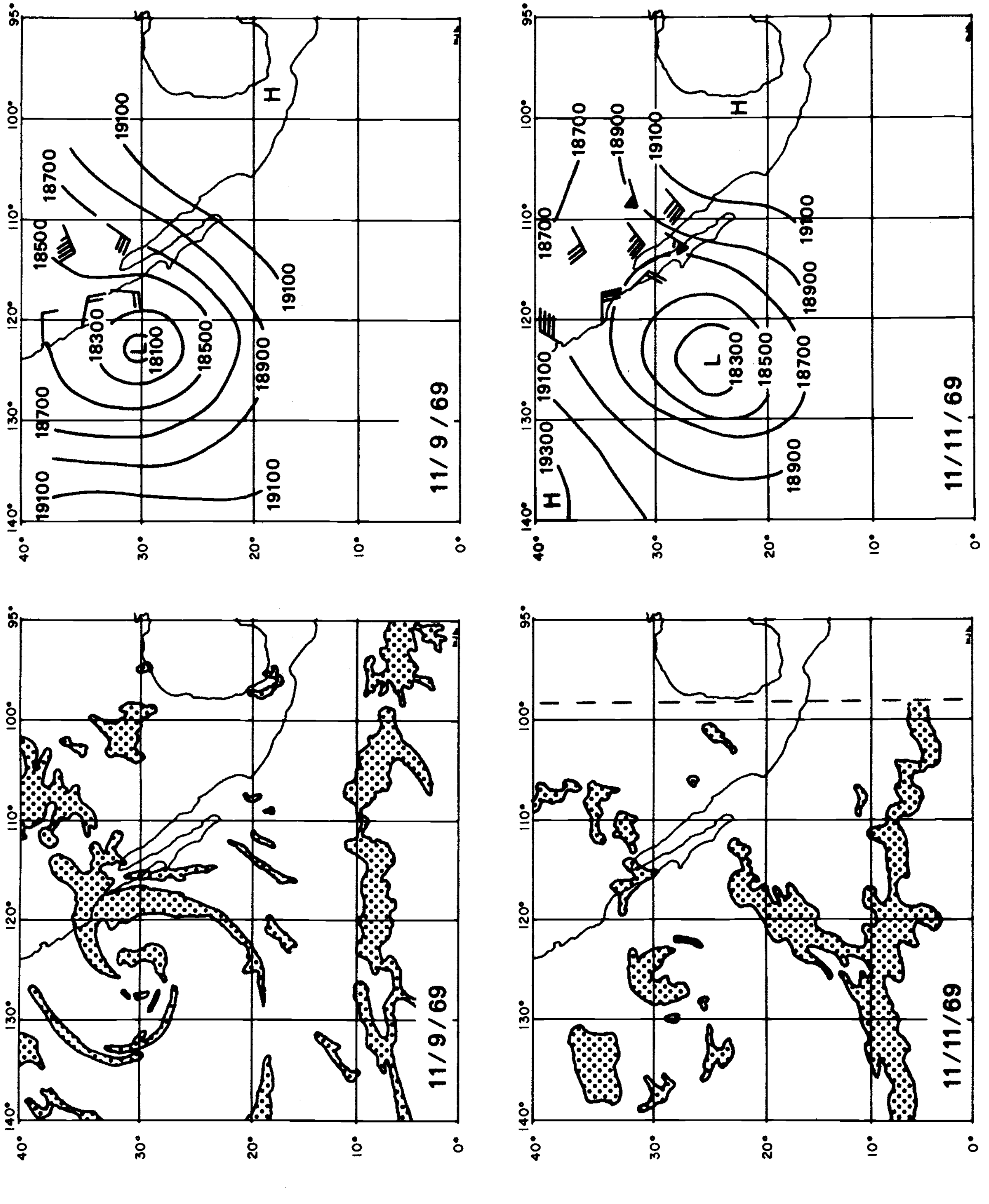
11/9/69
11/11/69
11/9/69
11/11/69
18100
18300
18500
18700
18900
19100
19300
L
H
95°
100°
110°
120°
130°
140°
40°
30°
20°
10°
0°

Figure 8.

Figure 9.

Distribution of major cloud clusters (redrawn from actual ESSA satellite photographs) in the eastern North Pacific; and 12Z, 500 mb charts for the same days of November 13 and 15, 1969.

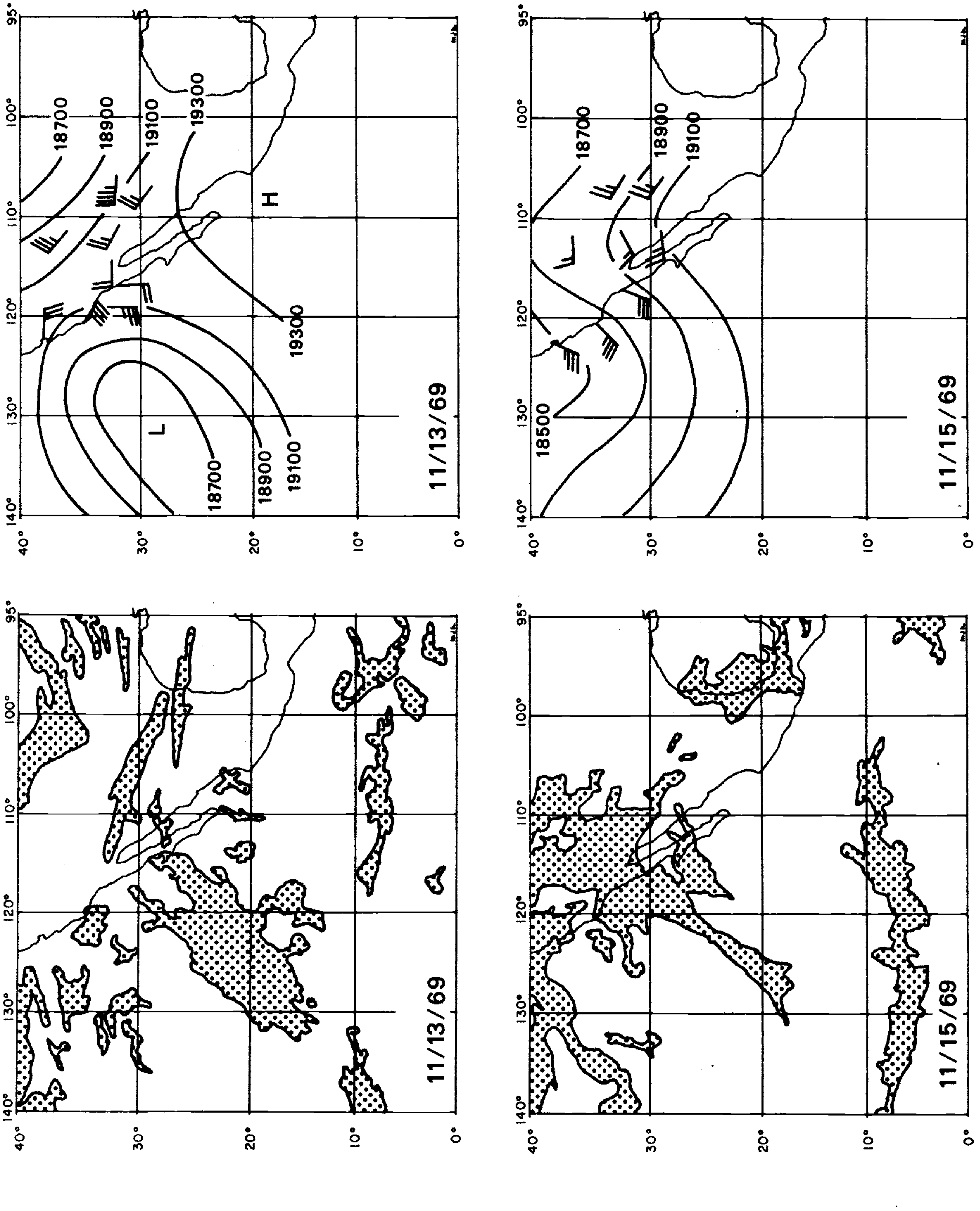95°
100°
110°
120°
130°
140°
40°
30°
20°
10°
0°
18700
18900
19100
19300
H
L
19300
18700
18900
19100
11/13/69
18700
18900
19100
18500
11/15/69
11/13/69
11/15/69

Figure 9.

Figure 10.

Total precipitation in Southern California and Arizona for November 9-12, 1969 (upper chart) and for November 14-17, 1969 (lower chart).

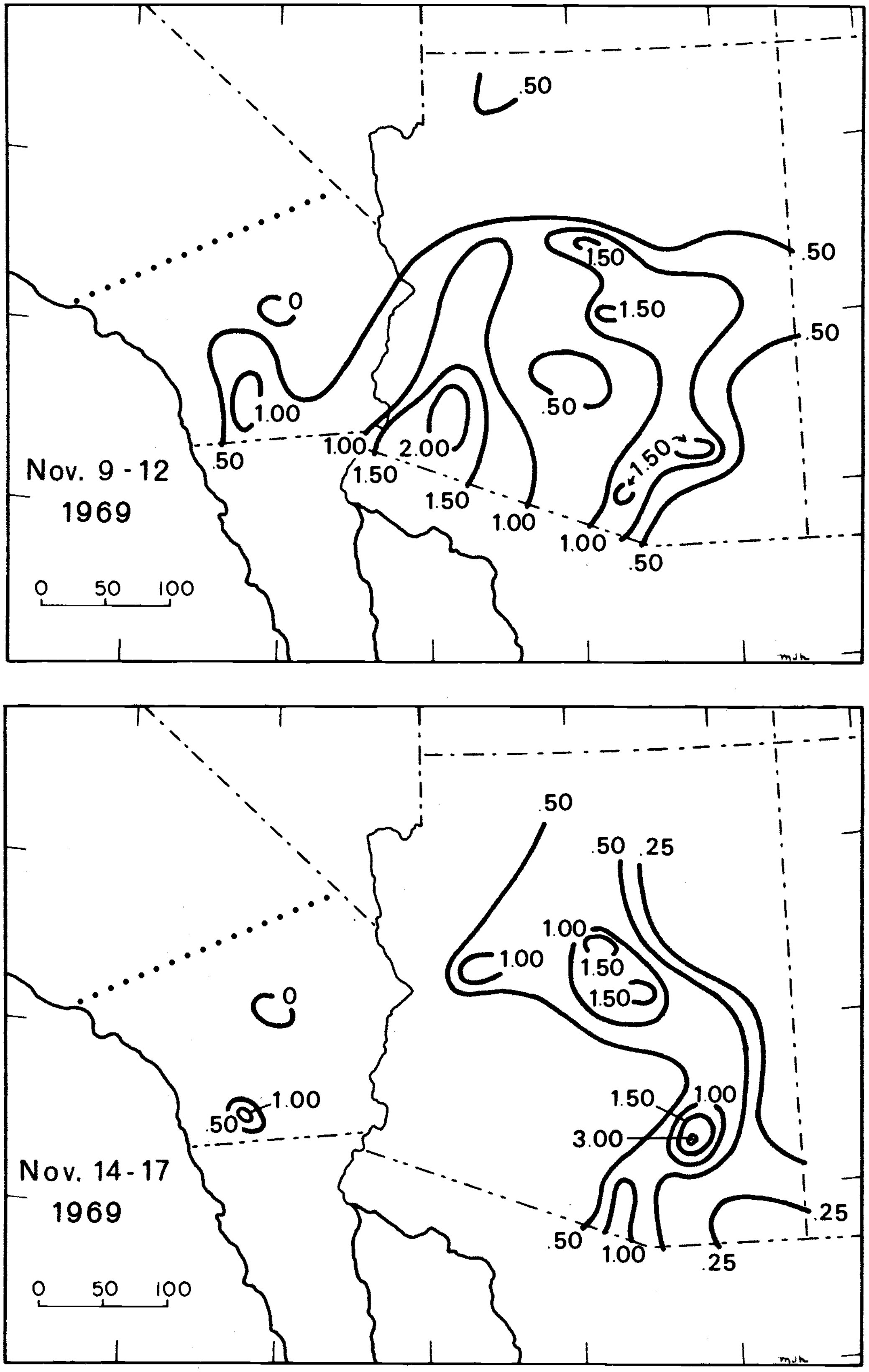
Nov. 9 - 12
1969
0 50 100
0
.50
1.00
1.50
2.00
.50
.50
Nov. 14-17
1969
0 50 100
0
.50
1.00
1.50
3.00
.25

Figure 10.

On November 11, the cloud mass centered at 20° N and 120° E was observed to be bulging northward from the ITCZ--apparently as a result of an interaction between the circulation of the cutoff low and the ITCZ (Figure 8). On November 13 and 15, the ITCZ derived cloudiness had expanded northward toward northwestern Mexico (Figure 9). This cloudiness expanded in size and reached into Arizona and Southern California on November 15. Extremely heavy precipitation occurred within this cloud mass, especially where orographic features accentuated convection (Figure 10). The cutoff low merged with a trough in the westerlies on the 15th. Thus, on the 15th and 16th, the movement of the cloud mass was associated with the trough rather than the cold upper cyclone. The moisture, however, had been advected into the region primarily through the interaction of the cutoff low with the ITCZ. A comparison of the upper and lower charts of Figure 10 indicates that precipitation from cloud masses derived from the ITCZ can be as high as precipitation associated with the spiral bank cloudiness of the cold upper cyclone.

PRECIPITATION FROM CUTOFF LOWS

As with tropical storm rainfall, the precipitation from cutoff lows can vary spatially and temporally throughout the study region. The variance of precipitation intensities tends to be dependent upon the time of day the moisture arrives, as well as upon the topography of the surrounding region. In order to assess these differences, the precipitation records for fourteen California and Arizona stations of different topographic configurations (Figure 11) were selected.

Figure 11.

Average annual precipitation in inches derived from cutoff lows during the period 1945-1972 for Southern California and Arizona. Stations analyzed were: 1) Holbrook, 2) Prescott, 3) Phoenix, 4) Yuma, 5) Tucson, 6) Death Valley, 7) Needles, 8) San Bernardino, 9) Los Angeles, 10) Yorba Linda, 11) Indio, 12) Blythe, 13) Cuyamaca, and 14) Brawley.

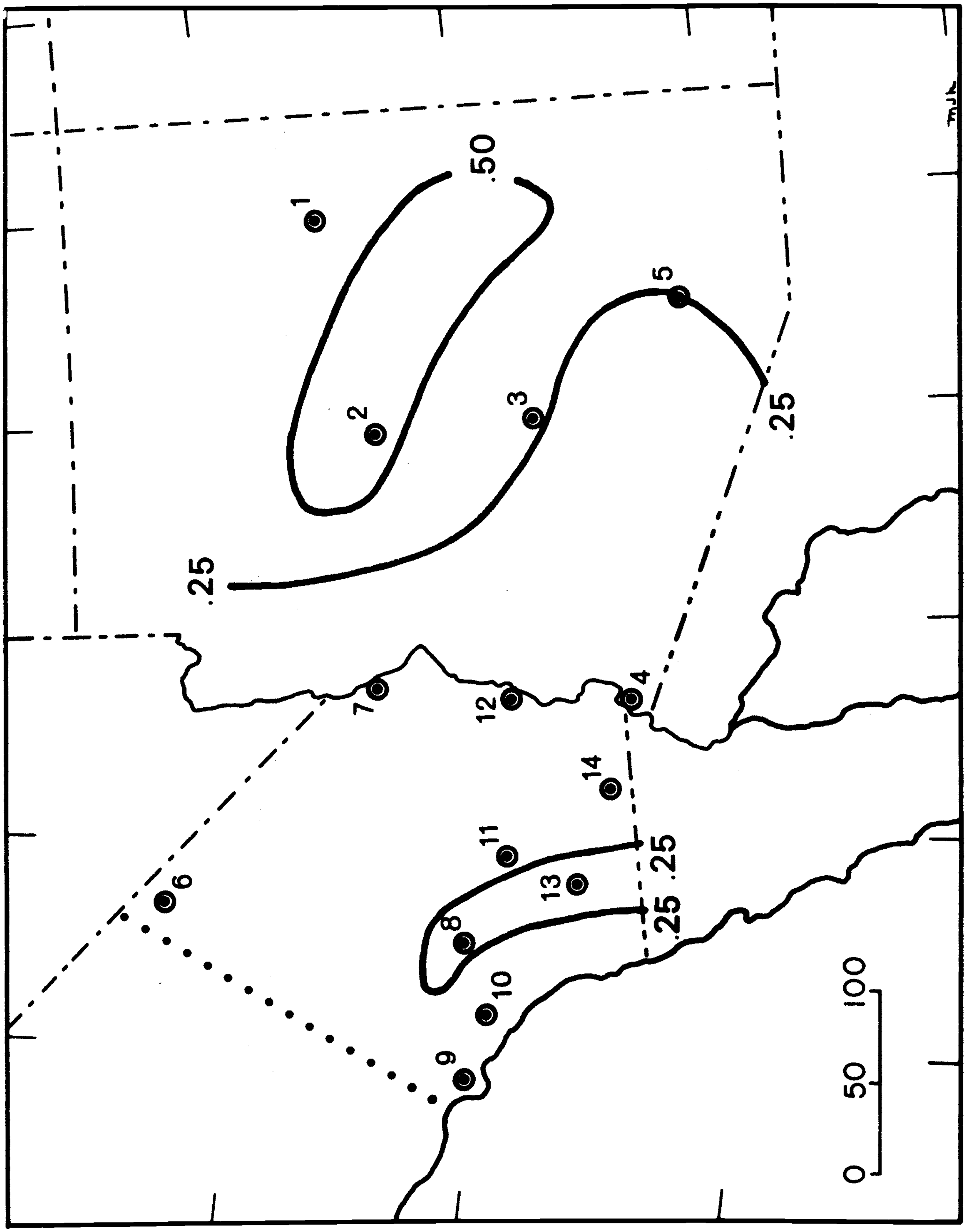

Figure 11.

Five stations were chosen in Arizona: Yuma, lowland desert; Phoenix, central desert of moderate elevation; Tucson, eastern upland desert; Holbrook, northeast plateau; and Prescott, high elevation central mountains. Nine stations were chosen in California: Indio, Blythe, Brawley, Needles--southern lowland desert; Death Valley, northern lowland desert; Cuyamaca, peninsular mountain ranges; San Bernardino and Yorba Linda, intermediate and coastal valley localities respectively; and Los Angeles, metropolitan coastal area.

All cutoff cyclones meeting the criteria described above were analyzed to determine possible influences on rain producing synoptic conditions of the Southwest. In a large number of cases, moisture associated with the cyclone arrived one or two days after a rainless period following the passage of the "parent trough." These preceding rainless days were helpful in distinguishing the cutoff low precipitation from that associated with the previous parent trough and associated cold front.

In many cases, precipitation again occurred two or three days after the cutoff cyclone had merged with a trough entering the western United States. This precipitation was excluded from the daily precipitation tabulations, even though the precipitation could have been derived from moisture advected northeastward by the former cutoff low (as in the manner described in the previous section).

The average annual precipitation due to cutoff lows is given in Figure 11. This figure clearly indicates that the amount of rainfall associated with cold upper cyclones is highly dependent upon topographic features. The heaviest precipitation totals are to be found in the mountains of Southern California and central Arizona. The percentage of annual precipitation due to cutoff lows indicates a fairly uniform and relatively low yearly amount of precipitation due to cutoff lows. It should be noted, however, that these cyclones are most common in the spring and fall. Thus, they are important sources of precipitation during the usually dry seasons between the extra-tropical cyclone precipitation of winter, and the monsoon rains of July to early September. Seasonal percentages of cutoff low precipitation based on total moisture for the months of May-June and September-November, would have been much longer.

Tables 2 and 3 give the yearly amount of cutoff low precipitation, as well as the percentage of total annual precipitation from cutoff lows. These tables clearly indicate that in some years cold upper low precipitation can be as high as 60 percent of the total annual precipitation. This moisture can be of great importance to the biota of the Southwest.

DISCUSSION

Present data suggest the positive 700 mb height anomalies are frequently found above the eastern extremity of anomalously warm pools of water. In this case warm sea surface temperatures between the dateline and 130° or 140° W would favor ridging along the west coast (Namias, 1968), with a well-developed Aleutian low being displaced southwest of its normal position (Namias, 1968). It could be hypothesized therefore, that ridging along the west coast precludes the movement of extratropical storms into California and Oregon, while

Table 2. Total annual amount of precipitation from cutoff lows, including percentage of annual precipitation from cutoff lows.

YEARLY CUTOFF LOW PRECIPITATION IN ARIZONA

YEAR	Holbrook		Phoenix		Prescott		Tucson University of Arizona		Yuma	
	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual
1945	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0
1948	0	0	.11	2	.30	2	.06	1	0	0
1949	.75	8	.22	3	.41	2	.07	1	.85	M
1950	.05	1	.68	17	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	0	0
1952	.77	7	.11	1	.18	*	.22	2	0	0
1953	0	0	.01	*	.15	1	.22	3	0	0
1954	.17	18	0	0	0	0	0	0	0	0
1955	1.84	30	.95	9	1.87	10	.31	2	0	0
1956	0	0	0	0	0	0	0	0	0	0
1957	.37	3	.08	1	.76	3	.28	2	0	0
1958	.60	9	.03	3	1.28	5	.05	*	0	0
1959	2.18	22	.74	8	1.11	6	.59	4	.06	3
1960	1.72	29	.57	16	1.21	6	.46	4	.01	*
1961	.02	*	0	0	.02	*	.27	2	.06	2
1962	0	0	0	0	0	0	0	0	0	0
1963	.41	4	1.43	19	.85	4	0	0	1.15	21
1964	.84	9	.05	1	.70	5	.17	1	0	0
1965	.05	*	0	0	0	0	0	0	0	0
1966	.90	15	.54	7	.95	6	.62	.4	.03	1
1967	.20	1	.44	5	1.12	5	.10	1	0	0
1968	.21	2	.35	5	.85	7	.18	1	0	0
1969	1.76	21	.62	9	2.71	12	1.35	19	2.41	63
1970	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0
1972	M	M	2.39	21	3.52	14	2.36	15	.61	15
1973	0	0	0	0	0	0	0	0	0	0
Total	12.84		9.32		17.99		7.31		5.18	
Average	.46	6.4	.32	4.3	.62	3.0	.25	2.1	.18	3.8

Table 3. Total annual amount of precipitation from cutoff lows, including percentage of annual precipitation from cutoff lows.

YEARLY CUTOFF LOW PRECIPITATION IN CALIFORNIA

	Blythe		Brawley		Death Valley		Indio		Los Angeles	
YEAR	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual
1945	-	0	-	0	-	0	-	0	-	0
1946	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0
1948	-	0	-	0	.04	M	-	0	T	0
1949	-	0	-	0	-	0	-	0	.46	4
1950	-	0	-	0	-	0	-	0	-	0
1951	0	0	0	0	0	0	0	0	0	0
1952	-	0	-	0	-	0	-	0	-	0
1953	-	0	-	0	-	0	-	0	.23	5
1954	-	0	-	0	-	0	-	0	-	0
1955	-	0	-	0	-	0	-	0	-	0
1956	-	0	-	0	M	M	-	0	.12	1
1957	-	0	-	0	.07	M	-	0	.04	*
1958	-	0	-	0	M	M	-	0	-	0
1959	-	0	-	0	-	0	-	0	-	0
1960	.35	11	.26	19	M	M	.48	36	1.02	10
1961	-	0	.02	1	-	0	-	0	-	0
1962	0	0	0	0	0	0	0	0	0	0
1963	1.20	19	.30	12	M	M	1.21	25	.57	4
1964	-	0	-	0	-	0	.07	4	-	0
1965	-	0	-	0	.09	2	-	0	-	0
1966	.76	20	1.28	50	.05	6	.22	1	-	0
1967	-	0	.01	*	.14	10	-	0	.01	0
1968	.20	16	-	0	-	0	.20	9	.13	1
1969	1.02	31	.73	24	M	M	.59	22	.03	0
1970	0	0	0	0	0	0	0	0	0	0
1971	-	0	-	0	-	0	-	0	-	0
1972	-	0	.40	18	.54	24	.41	36	1.77	24
1973	-	0	-	0	-	0	-	0	-	0
Total	3.53		3.00		.93		3.18		4.38	
Average	.12	3.3	.10	4.3	.04	1.91	.11	4.6	.15	1.7

Table 3. (continued) Total annual amount of precipitation from cutoff lows, including percentage of annual precipitation from cutoff lows.

YEARLY CUTOFF LOW PRECIPITATION IN CALIFORNIA

YEAR	Needles		San Bernardino		Yorba Linda		Cuyamaca	
	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual	Σ inches	% annual
1945	-	0	-	0	-	0	-	0
1946	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0
1948	-	0	-	0	-	0	-	0
1949	.01	0	1.26	5	.32	M	1.85	5
1950	-	0	-	0	-	0	-	0
1951	0	0	0	0	0	0	0	0
1952	-	0	-	0	-	0	-	0
1953	-	0	.49	6	.34	6	.47	2
1954	-	0	-	0	-	0	-	0
1955	-	0	.64	4	.83	7	-	0
1956	-	0	.47	4	.20	1	-	0
1957	.07	1	.86	4	.14	1	1.54	3
1958	-	0	-	0	-	0	-	0
1959	-	0	-	0	-	0	-	0
1960	1.08	34	1.79	19	1.36	14	1.17	4
1961	-	0	-	0	-	0	-	0
1962	0	0	0	0	0	0	0	0
1963	1.53	34	1.58	9	.76	5	1.88	6
1964	.02	1	-	0	-	0	-	0
1965	.06	1	-	0	-	0	-	0
1966	T	0	.13	*	.33	2	1.46	3
1967	-	0	.01	0	-	0	-	0
1968	-	0	.04	1	.02	1	.09	1
1969	1.02	29	.07	2	.06	2	2.02	4
1970	0	0	0	0	0	0	0	0
1971	-	0	-	0	-	0	-	0
1972	.32	10	.34	4	M	M	3.05	13
1973	-	0	-	0	-	0	-	0
Total	4.10		7.68		4.36		13.53	
Average	.14	3.8	.27	2.0	1.6	1.4	.47	1.4

cutoff low formation is favored in the southwestern United States. Thus, a fall or spring with numerous cutoff cyclones may be typified by a decrease in a number of extratropical lows and fronts approaching California and Oregon. In a normal fall or spring, however, the adjusting upper-level flow probably favors cutoff low formation only during a few days with more frequent frontal passages during other periods.

SUMMARY AND CONCLUSIONS

Data presented within this report indicate that upper-level cutoff lows occur during the normally dry months of May, June, September, October, and November. These upper-level cold lows occurring south of the westerlies (Palmén-Newton type d) are fairly infrequent in the Southwest with normally three occurring each year. This low frequency of occurrence precludes an analysis of major year to year changes in storm totals. However, atmospheric patterns associated with cold upper cyclones (teleconnection maps of O'Connor) suggest that mid-tropospheric lows are common in the Southwest when ridging occurs offshore along longitudes 130° W and 140° W.

Though the annual amount of precipitation from these disturbances is fairly light (.25 inches to .50 inches) the timing of these cold low rains is such that a large percentage of the monthly precipitation in May and June, and again in September, October, and November is due to these storms. A detailed study of individual cold upper cyclones in the past few years (using satellite data) has indicated that cutoff lows often induce a northward flow of equatorial air towards the Southwest. Precipitation associated with this advection process may not reach the Southwest until three or five days after the cutoff cyclone has left the region. No assessment has been made of the amount of precipitation associated with this post-storm precipitation, though an example given indicates heavy rains (> one inch) can occur within the advected air mass.

REFERENCES

Atkinson, Maj. G. D., 1971: Forecasters Guide to Tropical Meteorology. Air Weather Service (MAC), U. S. Air Force Tech. Rept., 240.

Blasing, T. J., 1974: Methods for analyzing climatic variations in the North Pacific sector and western North America for the last few centuries. Ph.D. Thesis (submitted), University of Wisconsin, Madison, Wisconsin.

Bryson, Reid A., and William P. Lowry, 1955: Synoptic climatology of the Arizona summer monsoon. U. S. Air Force Contract AF 19 (604)-992.

Douglas, A. V., 1972: The climatology of northeastern Pacific tropical storms and hurricanes. Interim. Rept., NOAA Contract 1-35241, Tree-Ring Laboratory, University of Arizona, Tucson, Arizona, 28 pp.

Douglas, A. V., and H. C. Fritts, 1973: Tropical Cyclones of the eastern North Pacific and their effects on the climate of the western United States. Final Rept., NOAA Contract 1-35241, Tree-Ring Laboratory, University of Arizona, Tucson, Arizona, 39 pp.

Korte, A. F., D. L. Jorgensen, and W. H. Klein, 1969: Charts giving station precipitation in the Plateau States from 850- and 500- millibar lows during winter. Technical Memorandum WBTM TDL 25, U. S. Dept. of Com., ESSA Weather Bureau, Washington, D. C., 71 pp.

Namias, J., 1960: Long-range forecasting of the atmosphere and its oceanic boundary--an interdisciplinary problem. Calif. Mar. Res. Comm., CalCOFI Rept., 12, 29-42.

O'Connor, J. F., 1969: Hemispheric teleconnections of mean circulation anomalies at 700 millibars. U. S. Weather Bureau Technical Report No. 10, U. S. Dept. of Com., Silver Spring, Maryland, 103 pp.

Palmén, E., and C. W. Newton, 1969: Atmospheric Circulation Patterns. New York, Academic Press, 603 pp.

Pyke, D. B., 1972: Some Meteorological Aspects of the Seasonal Distribution of Precipitation in the Western United States and Baja California. Los Angeles, University of California Water Resources Center Contribution No. 139, 205 pp.

Ramage, C. S., 1961: The subtropical cyclone. Rept. No. 15, Hawaii Institute of Geophysics, 26 pp.

Sands, R. D., 1966: A Feature of Circulation Approach to Synoptic Climatology Applied to Western United States. University of Denver, Dept. of Geography, Tech. Rept. 66-2, 332 pp.

Simpson, R. H., 1952: Evolution of the Kona storm, a subtripical cyclone. J. Met., 9 (1), 24-35.

U. S. Weather Bureau, Air Weather Service, ESSA and NOAA, 1943 et seq: Daily Series Synoptic Weather Maps, Part I, Northern Hemisphere Sea-Level and 500 Millibar Charts (plus Historical Weather Maps). Washington, D. C., U. S. Government Printing Office.