On the Relation of the Latitude and Strength of the 500 Millibar West Wind along 110 Degrees West Longitude and the Occurrence of Hail in the Lee of the Rocky Mountains

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ON THE RELATION OF THE LATITUDE AND STRENGTH OF THE 500 MILLIBAR WEST WIND ALONG 110 DEGREES WEST LONGITUDE AND THE OCCURRENCE OF HAIL IN THE LEE OF THE ROCKY MOUNTAINS

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ABSTRACT

The 500-millibar geostropic west wind component was computed at five degree intervals along 110 degrees W longitude. The differences in departures from normal values were compared for days with and without hail in the Colorado State University network during 1959 and 1960, and for Alberta for 1960.

For Colorado, the data suggest the passage of a "Relative Velocity Maxima" on days with hail during May. Later in the season hail days occurred during periods of decreasing west-wind velocity component.

During 1960 in Alberta, "heavy" hail occurred with a mean 500-millibar west wind component having two relative velocity maxima, one north and another south of Alberta. This pattern, deduced from the mean flow, is in agreement with published case histories of Alberta hailstorms.

In both geographic locations, the changes in west-wind velocity component indicate a relative increase in positive anomaly south of the latitude of hail occurrence during periods of hail.

These results indicate the importance of including the broad-scale circulation in connection with studies of local phenomena such as hail.

Relating the broad-scale circulation to the local phenomena is essential in order to utilize numerical forecasts of wind and pressure fields for forecasts of local severe weather.

INTRODUCTION

Recent advances in computer technology have permitted rapid strides to be made in numerical forecasting procedures. The procedures, however, are in general concerned with wind, temperature, and pressure fields of the atmosphere. Even if perfect prognostic pressure charts were prepared, complete forecasting skill would not be attained because of a lack of knowledge of the interrelation between weather processes and the general circulation parameters. This study is concerned with the relation of the occurrence of hail in the lee of the Rocky Mountains and the latitudinal distribtuion and strength of the 500 millibar west wind component along 110 degrees west.

OBJECTIVES

The objective of this study was to attempt to relate the occurrence or non-occurrence of hail in portions of the regions in the lee of the Rocky Mountains to the latitudinal position and strength of the 500 millibar west wind along 110 degrees west. A better understanding of this relationship should permit improved forecasts of hail as a severe weather phenomenon as increased skill is gained in prediction of upper-level wind and pressure fields.

METHOD

Riehl and others (1)[*] have pointed out the importance of the zonal wind distribution in forecasting in middle latitudes and have classified weather patterns according to the northward or southward drift of relative maxima and minima. In addition, they have suggested techniques for the calculation and representation of the zonal wind profile. A modification of this procedure was used in a more recent publication (2) to illustrate how a maximum west wind was correctly forecast to exist at a particular latitude from extrapolation of the trends of relative maxima and minima. Such extrapolation of relative maxima and minima offers some encouragement for possible use of a time-section of zonal wind speed as a forecasting aid, provided some relationship can be found between the zonal westerly wind and the weather phenomenon for which forecasts are desired.

In both the above cases the zonal westerly winds were computed for a region of the earth consisting of more than 90 degrees longitude span. The present study is a modification and a simplification of the above procedures in that the zonal wind component was considered along one longitude line only - at 110 degrees west longitude.

Time sections of the zonal wind speeds at 110 degrees west longitude have been prepared for the spring and summer seasons of 1959 through 1961. Examination of these time sections indicate that on some occasions relative maxima and minima can be identified in a manner similar to those which appear when more than a 90 degree longitude span is considered. Figure 1 shows an example of such a time section for the period

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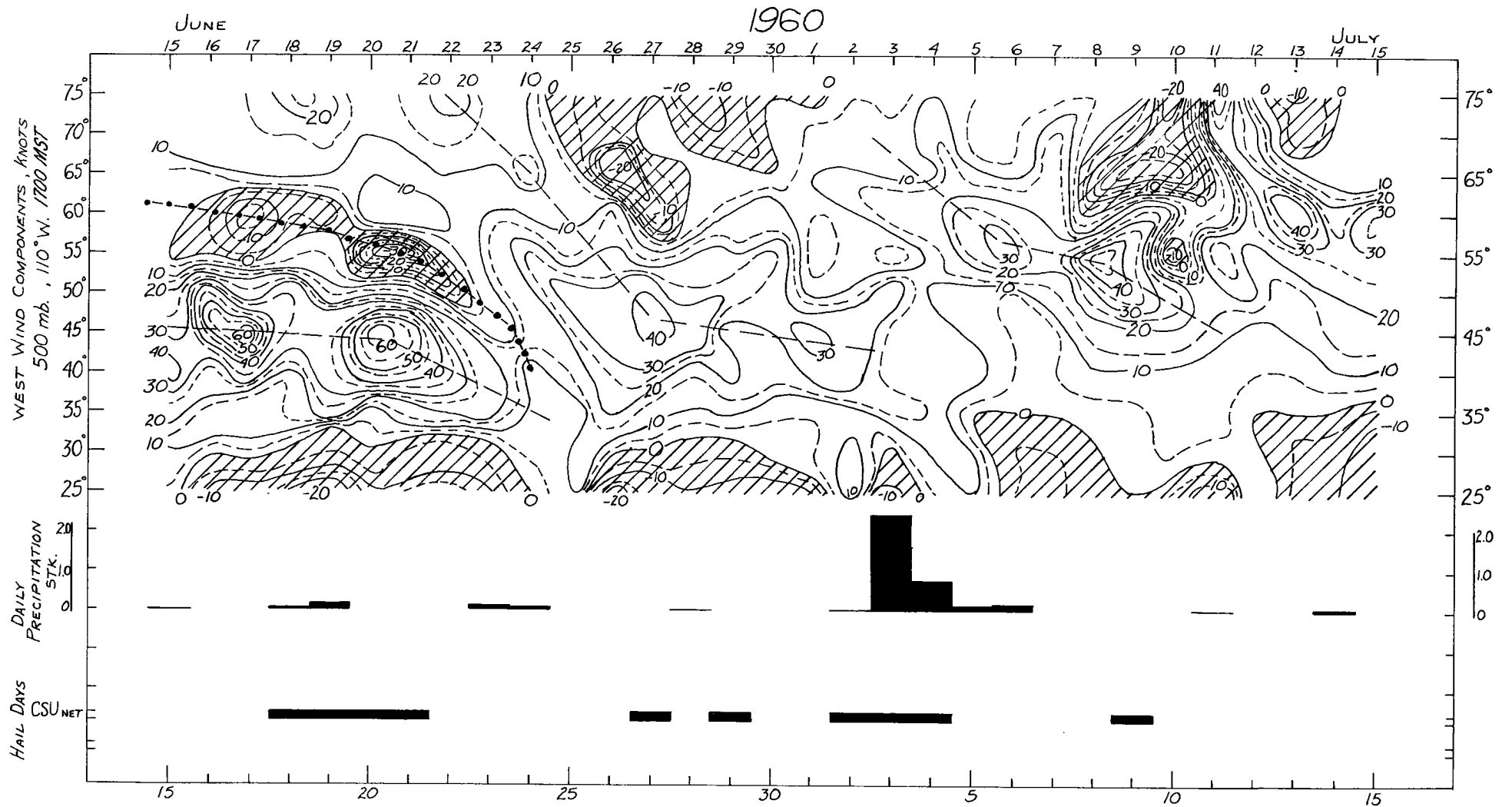*Numbers refer to appended references.

FIG. 1. TIME SECTION OF GEOSTROPHIC ZONAL WIND SPEED (KNOTS) AT 500 MB FOR 15 JUNE — 15 JULY, 1960. WINDS WERE DETERMINED ALONG 110°W. DASHED LINES INDICATE RELATIVE MAXIMA, AND DOTTED LINES RELATIVE MINIMA OF ZONAL WIND SPEED. DAILY PRECIPITATION IS SHOWN FOR STERLING, COLORADO (STK). "DAYS WITH HAIL" ARE DAYS FOR WHICH 3 OR MORE REPORTS OF HAIL WERE OBTAINED FROM THE COLORADO STATE UNIVERSITY HAIL REPORTING NETWORK.

15 June through 15 July 1960. Data such as that shown for Figure 1 have been examined for a qualitative relationship between the zonal winds and weather phenomena, such as amount of precipitation and the occurrence of hail in northeastern Colorado. Figure 1 shows, for example, that precipitation occurred on four days out of seven in the period from 18 June through 24 June as a relative maxima approached 40 degrees north latitude from the north. During the period 25 through 30 June no precipitation of consequence occurred as the strength of the zonal westerlies at 40 degrees north latitude decreased. Major amounts of precipitation were received on 3 and 4 July as the relative maxima again approached 40 degrees latitude from the north.

A "hail day" within the Colorado State University hail observing network, for purposes of this study, was defined as a day on which there were three or more reports on hail occurrences in northeastern Colorado, in a region north of 40 degrees north and east of 104 degrees west. "Hail days" occurred primarily between the 18th and 21st of June and the 1st through 4th of July, with other scattered "hail days" as shown in Figure 1.

The basic data for Figure 1 were obtained by computing the geostrophic west wind component at 500 millibars along 110 degrees west for each five degrees of latitude between 30 degrees north and 70 degrees north. Data were obtained from the 00Z data from the daily weather map (3). The average values of this west wind component for each of the years 1959 through 1961 and for normal values (4) are shown in Table 1. Table 1 shows that marked differences occur from 30 degrees north to 70 degrees north, and that large variations occur from year to year along a particular latitude. For example, at 65 degrees north latitude for the month of May variations in the mean wind speed from 1.7 to 23 knots occurred during

Lat Deg N	May				June				July				August			
	1959	1960	1961	*TP21	1959	1960	1961	*TP21	1959	1960	1961	*TP21	1959	1960	1961	*TP21
70	6.6	7.4	14.1	12	5.7	11.9	8.7	13	7.9	9.8	11.6	9	-0.3	9.3	15.9	12
65	17.3	1.7	23.0	13	13.7	3.5	13.7	14	16.4	12.2	12.9	13	11.1	18.6	20.9	14
60	17.2	3.1	12.5	18	15.5	2.4	12.6	14	19.9	22.5	9.2	16	16.1	16.1	23.6	15
55	15.5	13.2	7.9	20	24.1	13.0	14.1	13	20.9	24.9	11.6	18	20.4	16.6	24.8	20
50	9.6	20.9	7.1	17	26.3	29.1	16.8	12	25.5	24.1	20.3	18	35.4	21.5	24.0	20
45	11.7	10.6	20.4	15	22.6	29.6	14.2	15	24.0	14.7	20.0	18	27.7	24.8	14.3	14
40	24.0	14.4	19.2	16	13.5	20.8	10.1	19	13.2	8.0	9.8	17	14.9	18.4	6.9	13
35	26.4	22.5	17.2	17	6.5	10.3	4.9	18	0.3	0.1	-1.2	10	5.1	5.7	-.7	10
30	24.2	24.5	17.1	18	4.8	2.9	0.2	7	-7.6	-4.1	-8.8	0	-1.3	-4.6	-5.7	0
Total	152.5	118.3	138.5	136.0	132.7	123.5	95.3	125.0	120.5	112.2	85.4	119	129.1	126.4	124.0	118
Mean	16.9	13.1	15.4	15.1	14.7	13.7	10.6	13.9	13.4	12.5	9.5	13.2	14.3	14.0	13.8	13.1

*USWB Technical Paper 21, "Normal weather charts for the northern hemisphere."

Table 1. Average values of 500 mb west wind component (knots) for various latitudes at 110 degrees W.

the three-year interval studied. This is a variation of about 14 times and a departure from normal ranging from 13 percent of normal to 176 percent of normal. From these differences it is evident that a method of comparison is necessary which is not influenced by the year-to-year variation in the strength of the zonal westerly wind component. In order to compare between days with hail and days without hail the following procedure was used to define a difference in departures from normal in the westerly wind component along 110 degrees:

1) The average 500 mb geostrophic west wind component (x') was determined from reference (4);

2) The actual west wind component (x) was determined for each day;

3) The difference (x - x') was determined for each day;

4) Each day was classified as a hail day or a non-hail day;

5) For each of these two categories the mean difference Δ was determined. This procedure can be summarized by the following equation:

$$\Delta = \frac{\Sigma(x-x')_H}{n_H} - \frac{\Sigma(x-x')_{NH}}{n_{NH}} \qquad (1)$$

where,

Δ = difference in departures from normal of the geostrophic 500 mb west wind component along 110 degrees W.

x = 500 mb west wind component for a particular day.

x' = mean 500 mb west wind component from reference 4.

n = number of days.

This parameter Δ was used in studies of hail occurrences in the Colorado State University network.

For similar studies of Alberta hailstorms in 1960 the mean departures of the observed 500 mb westerly winds from the average values for the months were determined for days with hail and days without hail, as reported from the Alberta hail network (5). (Hail days were those listed by Thompson as major hail storms of 1960.) The average departures "d" used for the studies of hail in Alberta are defined by equations 2 and 3:

$$d_{NH} = \frac{\Sigma (x-\bar{x})_{NH}}{n_{NH}} \qquad (2)$$

$$d_H = \frac{\Sigma (x-\bar{x})_H}{n_H} \qquad (3)$$

where

d = Average departure of Westerly Geostrophic wind component at 500 mb from monthly mean.

$\bar{x}$ = monthly mean westerly component.

In equations 1, 2, and 3, the subscripts H and NH refer to days with and without hail, respectively.

In order to determine the changes that took place before a hail event, the values of "Δ" and "d" were also computed for the first days prior to hail (D-1), the second days prior to hail (D-2), and the third days prior to hail (D-3). These computations were made by obtaining a difference, "Δ" as defined by equation (1), and "d" as defined by equations (2) and (3), between (D-1) days and all other days, (D-2) days and all other days, etc.

RESULTS

Figure 2 shows the differences in departures from normal (Δ) of the westerly wind component at 500 millibars along 110 degrees west between days with and without hail.

Figure 2 shows that in May a maximum value of Δ exists at 55 degrees north for D-2. This maximum moves successively to 40 degrees north and 35 degrees north respectively, for D-1 and D (the day of hail occurrence). This suggests a maximum westerly wind moving rapidly from north to south, passing through the latitude of hail occurrence on the day before hail. This behavior of the maximum westerly wind in the mean is confirmed by studies of individual cases of hail occurrence in May in eastern Colorado.

This phenomenon does not appear in such a clear manner in the months of June, July and August. During June the value of Δ is at a minimum for each day, D-3 through D in the region 45 to 55 degrees north and increases at 35 degrees north from D-2 to D.

For the month of July the value of Δ decreases at 40 degrees N as D approaches. This suggests either a decrease in westerly wind component or an increase in the northerly wind component for days with hail in July. The latter explanation seems more reasonable in view of the tendency of hailstorms to move from north to south during July (6).
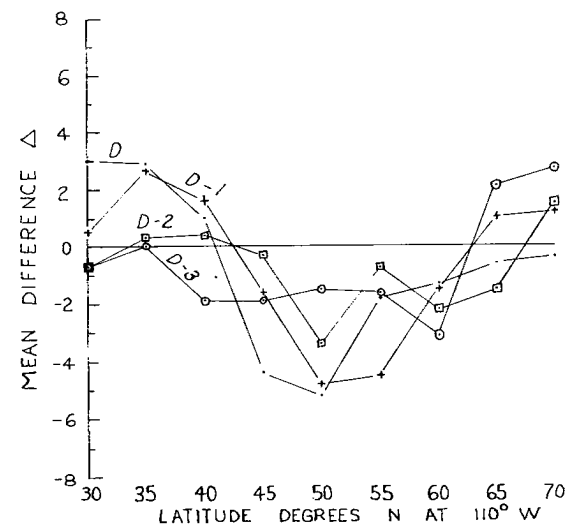
During August a tendency for the maximum Δ to move from north to south during the period preceding hail days is evident at latitudes of 70 to 55 north. This suggests a similar pattern at that latitude as was noted at 40 degrees north during May and can probably be interpreted as
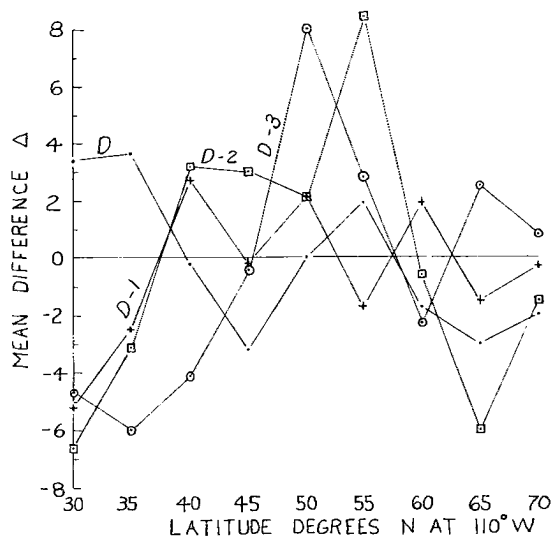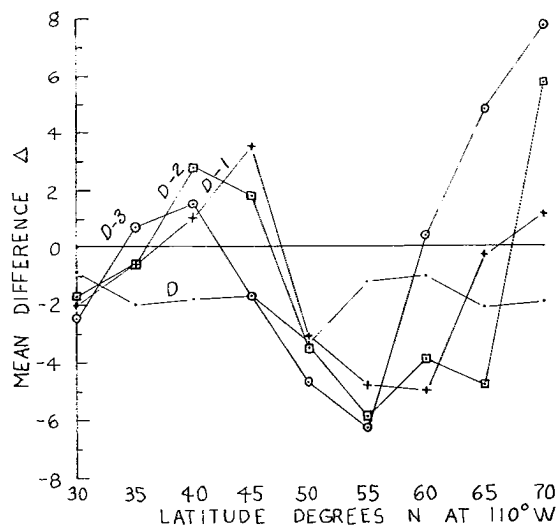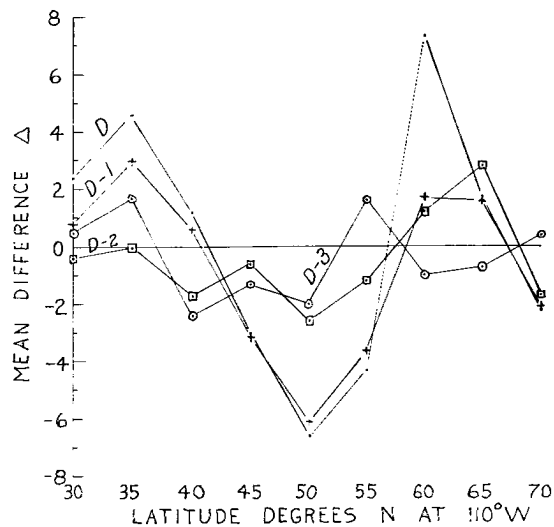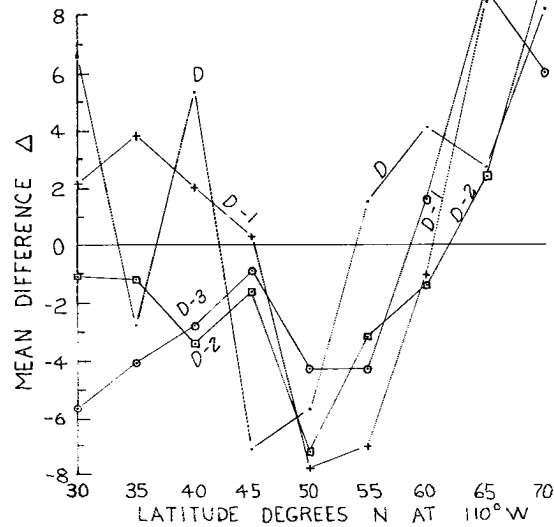
FIG. 2

HAIL DAYS IN NE COLORADO

DIFFERENCES IN DEPARTURES FROM NORMAL OF THE WESTERLY WIND COMPONENT (KNOTS) ALONG 110°W FOR THE PERIOD INDICATED

— ·— AVERAGE DEPARTURE FOR DAYS WITH HAIL (D) MINUS AVERAGE DEPARTURE FOR DAYS WITHOUT HAIL

—+— AVERAGE DEPARTURE FOR ONE DAY BEFORE HAIL (D-1) MINUS AVERAGE DEPARTURE FOR OTHER DAYS

—□— AVERAGE DEPARTURE FOR TWO DAYS BEFORE HAIL (D-2) MINUS AVERAGE DEPARTURE FOR OTHER DAYS

—○— AVERAGE DEPARTURE FOR THREE DAYS BEFORE HAIL (D-3) MINUS AVERAGE DEPARTURE FOR OTHER DAYS

HAIL DAY ≡ THREE OR MORE HAIL REPORTS (MAILED IN)

a rapidly moving relative maxima moving from north to south for the days of hail occurrences.

The season totals shown in Figure 2 show negative values of Δ between 45 and 60 degrees north and positive values at other latitudes.

For each of the months, May through August, and for the season, it can be noted that the difference in Δ values between 35 and 45 degrees north tends to increase prior to a hail day. If one defines the gradient of this difference as

$$\text{Gradient}_{40} = \Delta_{35} - \Delta_{45} \tag{4}$$

where

$$\text{Gradient}_{40} = \text{change of } \Delta \text{ at 40 degrees N}$$

and

$$\Delta_{35,45} = \text{values of } \Delta \text{ at 35 and 45 degrees N , respectively,}$$

then one observes an increase in gradient as shown in Table 2.

This tendency for an increased Gradient_{40} is evident in each month and also for the season.

Another feature common to each of the months and to the season that can be noted in Figure 2 are negative values of Δ between about 45 and 55 degrees north and positive values of Δ at the other latitudes.

The average departure of the 500 millibar westerly wind components along 110 degrees west from monthly means for 1960 for days with and without heavy hail in Alberta as computed by equations 2 and 3 are shown in Figures 3 and 4. From Figures 3 and 4, it can be noted that the average departures are much larger on days with heavy hail than for other days.

		Gradient$_{40}$ = Δ_{35} - Δ_{45}			
	May	June	July	August	Season
D - 3	-5.6	3.0	2.4	-3.2	1.9
D - 2	-6.3	.6	-2.4	.2	.6
D - 1	-2.3	6.1	-4.1	3.5	4.2
D	6.8	7.6	-0.3	4.3	7.3

Table 2. Changes in departures from normal west wind component across 40 degrees N latitude from the third day prior to a hail day (D - 3) to a hail day (D). Hail data are from northeastern Colorado.
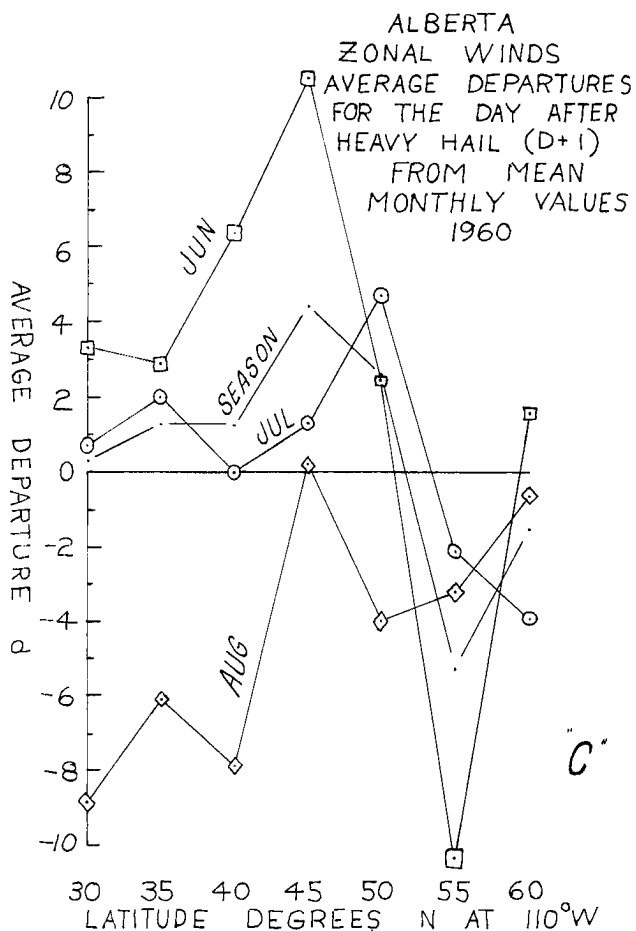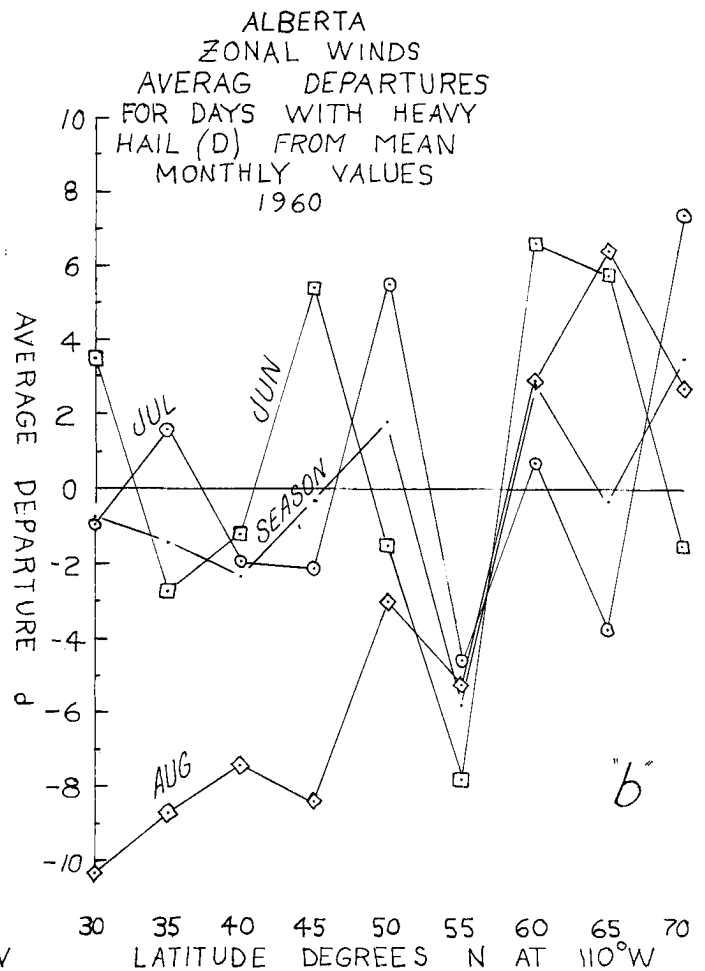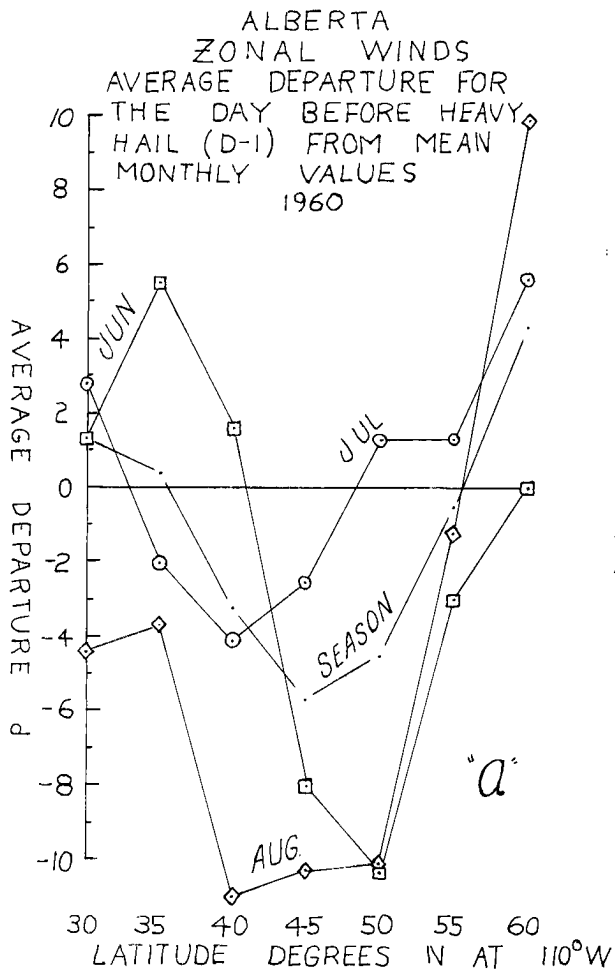
ALBERTA
ZONAL WINDS
AVERAGE DEPARTURE FOR THE DAY BEFORE HEAVY HAIL (D-1) FROM MEAN MONTHLY VALUES 1960

"a"

ALBERTA
ZONAL WINDS
AVERAG DEPARTURES FOR DAYS WITH HEAVY HAIL (D) FROM MEAN MONTHLY VALUES 1960

"b"

ALBERTA
ZONAL WINDS
AVERAGE DEPARTURES FOR THE DAY AFTER HEAVY HAIL (D+1) FROM MEAN MONTHLY VALUES 1960

"c"

FIG. 3

ALBERTA
ZONAL WINDS
AVERAGE DEPARTURE d
VS.
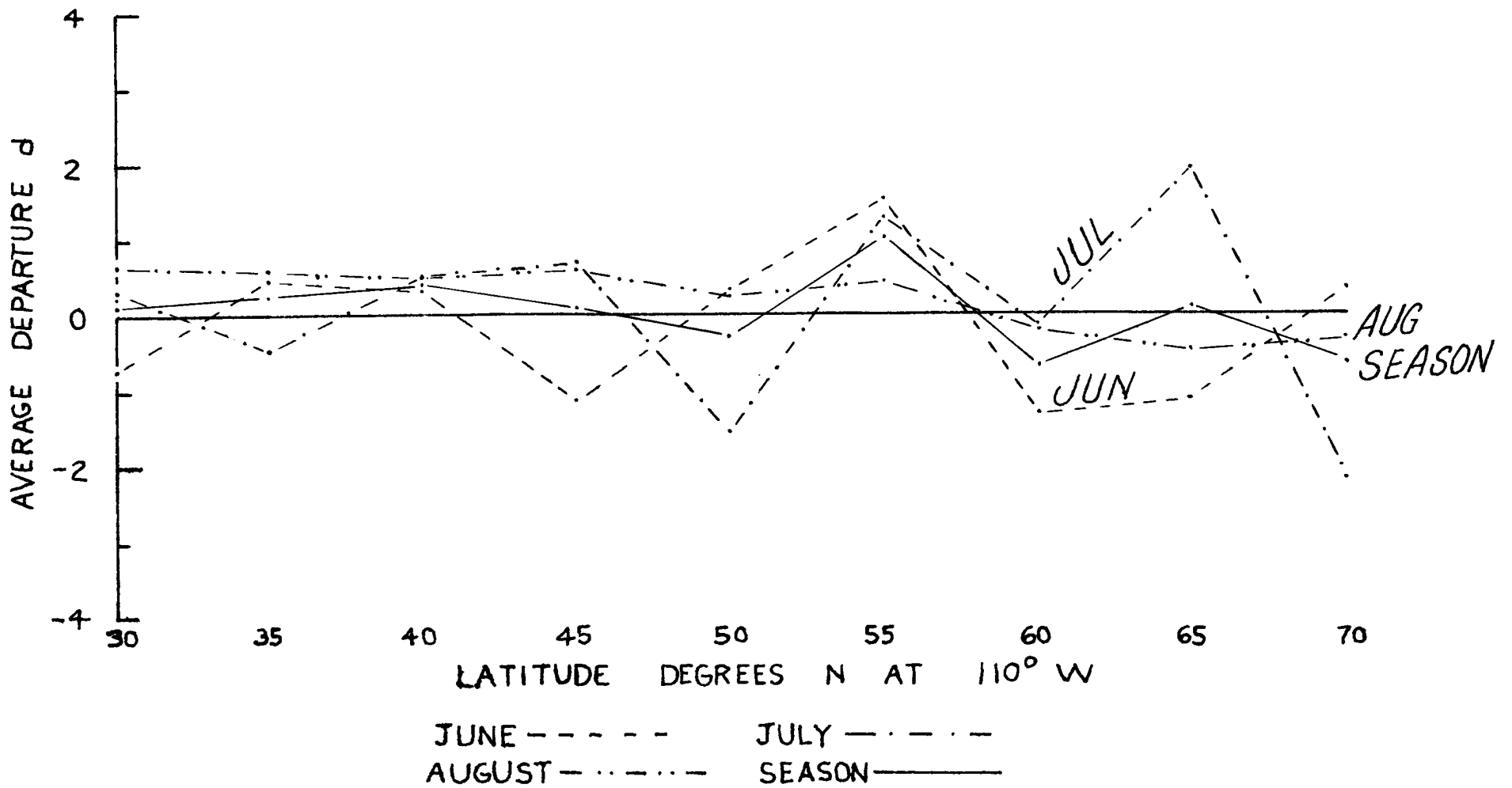LATITUDE DEGREES N AT 110°W

JUNE
JULY
AUGUST
SEASON

FIG. 4
ALBERTA
ZONAL WINDS
AVERAGE DEPARTURE FROM MEAN
MONTHLY VALUES FOR DAYS WITHOUT HEAVY HAIL
1960

From Figure 3b it may be noted that there are positive values of d at
50 and 60 degrees north with a minimum at 55 degrees. The Alberta
hail reporting region is bounded approximately by 50 and 60 degrees north
on the south and north respectively. From Figure 3b one would deduce a
500 millibar wind flow having two relative maxima, one to the north and
the other south of Alberta. This deduction is in agreement with the pattern
shown in a case history of a "heavy hail day - one of the worst storms in
1959," shown in Figure 5, and also by published data for the mean 500
millibar flow for 1700 MST for days with "severe turbulence" in Alberta
during June, July and August 1959 as shown in Figure 6. (Figure 12 of
reference 7.)

In addition to providing a pattern in 1960 which appears to be con-
sistent with data reported by Longley and Thompsen (7) for 1959, the
gradient change in Alberta (Table 3) corresponds to that observed in Colorado
(Table 2). For each of the months of June, July and August, and for the
season, "Gradient$_{55}$" as measured by the difference in departure between
50 and 60 degrees north latitude shows a more positive value for the day
after hail than for the day before heavy hail occurrence.

DISCUSSION OF RESULTS

The foregoing data illustrate a probable relation between the broad-
scale circulation patterns and the occurrence of a specific severe-weather
event, hail. It appears that the broad-scale pattern may provide a
necessary (but not sufficient) condition for hail occurrence in the lee
of the Rockies. The specific features that appear to be favorable for hail
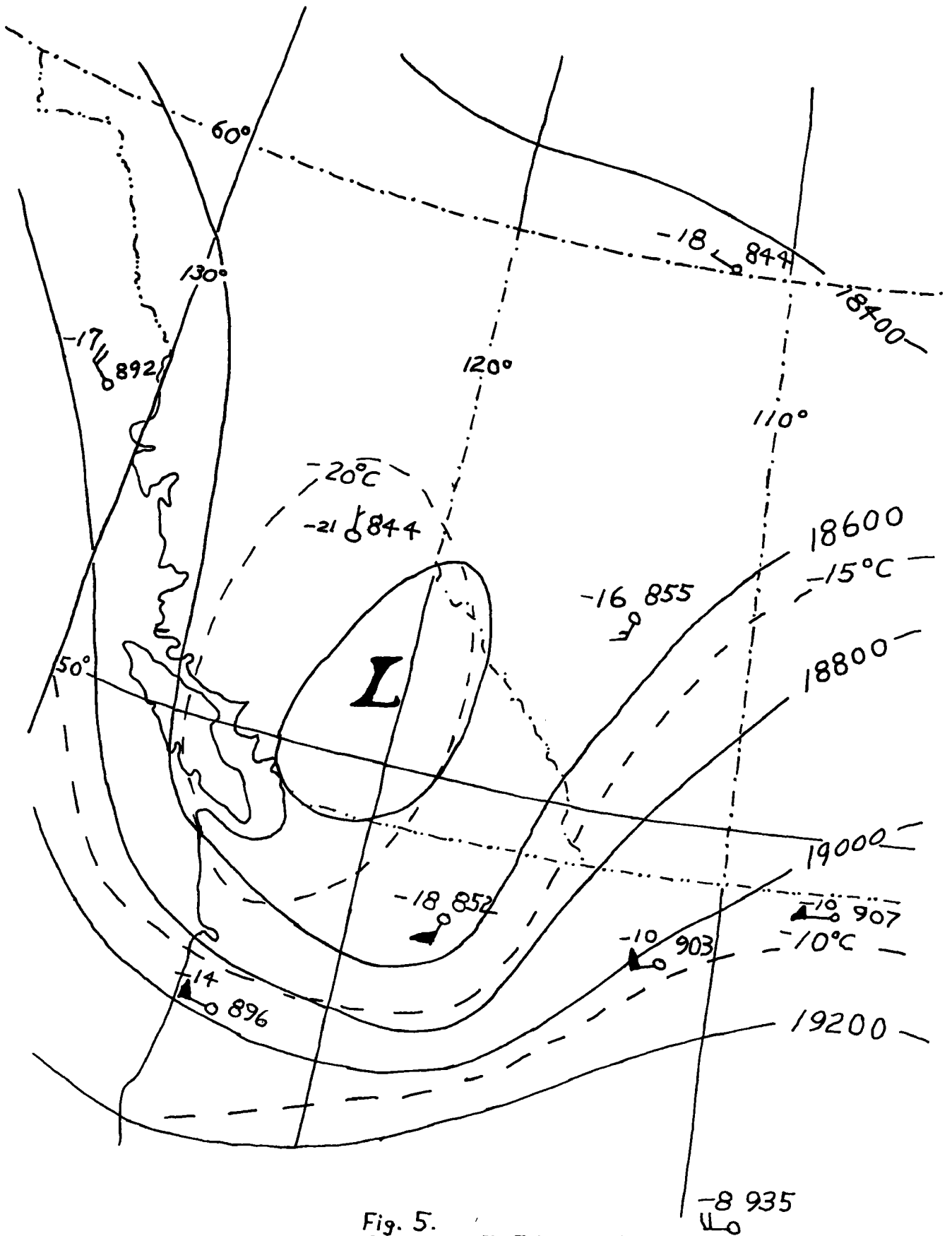occurrences are:

Fig. 5.
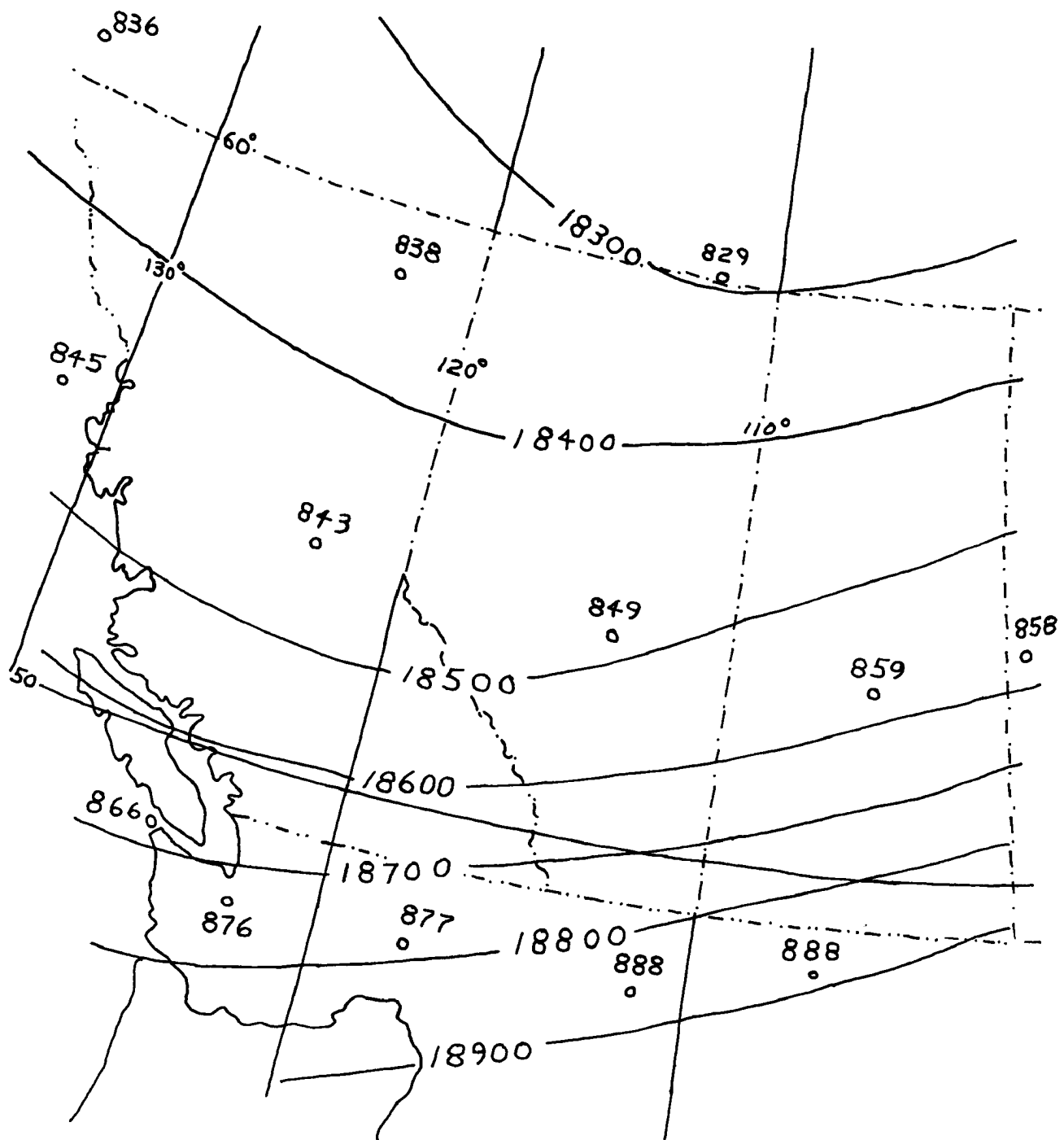500-mb map for 1700 MST, July 27, 1959

Fig. 6.
Mean 500-mb map for 1700 MST for days with severe turbulence
during June, July and August, 1959 (24 days).

	June	July	August	Season
	$\text{Gradient}_{55} = d_{50} - d_{60}$			
D - 1	-7.2	-4.4	-20.1	-8.7
D	-8.1	4.7	- 5.9	-8.7
D + 1	1.0	8.6	- 3.6	4.0

Table 3. Changes in departures of the westerly 500 mb wind component along 110 degrees W from the day before heavy hail (D - 1) to the day following heavy hail (D + 1) in Alberta.

1. Passage of a "Relative velocity maxima" in Colorado in May (Figure 2).

2. An increase in the positive anomaly south of the latitude of hail occurrence (for both Colorado and Alberta, as shown in Tables 2 and 3.)

These data also show a distinct contrast in that days without heavy hail in Alberta (Figure 4) show little latitudinal variation in departures of the zonal winds from average, as compared to days with heavy hail (Figure 3).

The data of Table 1 show that large departures from normal values of west wind occur from year to year. This fact emphasizes the hazard of any direct comparisons from one year to another without any consideration of large-scale circulation differences.

The indication of a relation between a "relative velocity maxima" and the occurrence of hail is consistent with the data of Dessons (8) who showed a relation between strong winds aloft and the occurrence of large hail.

Further study is needed to resolve some of the remaining questions. For example, if the wind shear associated with a "relative wind maxima" is important in hail formation, is it because of dynamic effects on a meso scale; or a result of deformation of the cumulonimbus; or perhaps associate with stability structure of the atmosphere?

The reason for the association between hail occurrences and a 500 mb west wind component deserves further study. In addition to the possible mechanisms suggested in the preceding paragraph, it is possible that the maximum 500 mb west wind is associated with the zone of the

polar front, and hence represents a latitude for favored passages of cyclones, which in turn trigger the severe weather.

Answers to the foregoing questions are needed in order to proceed from the conventional pressure-pattern prognostic chart presentation to improved forecasts of hail occurrence.

Finally, this study points out the importance of consideration of the larger-scale weather patterns, even when the item of particular interest is of a smaller scale, such as hail occurrences.

ACKNOWLEDGEMENT

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