RADAR CLIMATOLOGY OF HAIL STORMS
IN AND NEAR NORTHEASTERN COLORADO
15MAY - 31 JULY 1963
WITH COMMENTS ON THE RELATION OF
RADAR CLIMATOLOGY TO SELECTED SYNOPTIC PARAMETERS

by

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COLORADO STATE UNIVERSITY

FORT COLLINS, COLORADO

CIVIL ENGINEERING SECTION, FOOTHILLS CAMPUS

January 1964

Mr. Philip S. Brown, Manager
Crop-Hail Insurance Acturial Assn.
Room 700, 209 West Jackson Blvd.
Chicago 6, Illinois

Dear Mr. Brown:

I am pleased to transmit herewith the report "Radar Climatology of Hail Storms In and Near Northeastern Colorado, 15 May-31 July 1963, With Comments on the Relation of Radar Climatology to Selected Synoptic Parameters."

This report is changed in format from that in previous years. We have chosen to examine some of the data available from 1963 and previous years in order to attempt to better understand the factors involved in the development and movement of thunderstorms on a day-to-day basis, and to seek explanations for the marked variations in hail damage that occur from one year to another. These attempts have been successful only in part, but have helped to better understand the physical factors involved in hailstorms.

For ease in reading, the Summary and Conclusions are presented at the beginning of the report.

As in previous years, most of the support for the hail research at Colorado State University has been supplied by the National Science Foundation.

I wish to take this opportunity to thank the Association for their assistance in support of this research.

Sincerely yours,

Richard A. Schleusener

RAS/ezb

Richard A. Schleusener
Associate Research Engineer

SUMMARY AND CONCLUSIONS

The radar climatology of thunderstorms in northeastern Colorado was studied from 15 May-31 July 1963 with a 3 cm radar located at New Raymer, Colorado. Fewer hail events occurred in 1963 than in any previous year for which data are available (1959-63).

Significant features of the radar climatology of the thunderstorms in 1963 included the following:

1. Fewer radar echoes were observed than in the two preceding years.
2. Motion of cells from the northwest in July was not as common a feature as in preceding years.
3. Comparison with 1962 (a year of record-breaking hail frequency) indicates that a dominant feature in 1962 was a frequent storm path from the southwest quadrant. Motion of storms in 1963 was primarily from the west.

A forecast aid was derived for forecasting the occurrence and intensity of thunderstorms "today" from synoptic data available at 06z "today", the parameters used include the following:

1. Surface dew point change
2. Sea-level pressure
3. Sea-level pressure gradient
4. Change in sea-level pressure gradient
5. Wind direction at 500 mb.

Observations of thunderstorm genesis and movement in 1963 led to an hypothesis for favored zones for genesis of thunderstorms in regions of marked cyclonic curvature of surface isobars, and movement of the developed thunderstorms when the 500-mb wind flow is parallel to the surface isobars.

Average surface pressure patterns determined for 10 non-hail days and also for 10 hail days indicate that hail is favored during periods of lower pressure and stronger circulation than for the non-hail cases.

A study was made of records of hail damage to sugar beets in northeastern Colorado and the direction and speed of mean monthly 500-mb wind at Denver, Colorado. The results indicate that mean monthly winds cannot be used as indices of hail damage. However, there is a positive correlation between change in mean 500-mb wind speed from one month to the next and change in hail damage during the same period.

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Prepared for the Crop-Hail Insurance Actuarial Association

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Civil Engineering Section
Colorado State University
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INTRODUCTION

This report gives the results of three different phases of study of hail events in the high plains of northeastern Colorado. First a summary is given of the radar climatology of hailstorms in 1963, with comparative data for 1962 and 1961. Second, an objective forecast aid is presented for forecasting thunderstorm occurrence and intensity, and general comments are made on the small-scale synoptic patterns which appear to be important in the genesis and movement of thunderstorms. Finally, a review is made of the variation of average wind flow as measured at 500 mb as compared to crop-hail losses to sugar beets as determined from records of loss from the Great Western Sugar Company.

RADAR CLIMATOLOGY OF HAIL STORMS

Radar systems, data, and methods

Radar systems included in the total project were similar to those in 1962. These were the CPS-9 system at Lowry Air Force Base near Denver, the weather radar system of Atmospherics Incorporated located near New Raymer, and the vertical scanning system modified by Colorado State University and also located at New Raymer, Colorado.

The radar system furnished and operated by Atmospherics Incorporated provided the major portion of the data used to compile the information in this report. This was 3 cm equipment operating on a frequency of 9375 megacycles with a peak power of about 50 kw. Five separate ranges were available in steps of 4-10-20-80 and 200 nautical miles.

The weather radar system located at New Raymer included two indicators with 7" PPI presentation. One of these indicators was used for general storm tracking plus black and white still photographs of many of the more interesting precipitation echoes. The second indicator was used exclusively for time-lapse photographs with the camera pulsed by the rotation of the radar antenna (one frame every 12 seconds).

The radar system employs a tilt indicator which gives the vertical angle of the antenna. For general scanning, the antenna was usually kept on an angle of about $+1^0$ but was occasionally raised to its maximum angle of 35^0 when measurements of echo tops were desirable. Precipitation echoes were tracked and hail paths identified from the Rocky Mountains to points as far east as the maximum 200 nautical miles.

Equipment used for documenting certain information included a digital display and illuminated clock positioned around one of the PPI indicators and photographed by the time-lapse camera. The display allowed film documentation of time, date, antenna angle, and other information considered pertinent to the particular series of storms. Tape recorder unit for voice recording, map plotting facilities, 16 mm time-lapse camera, several still cameras (35 mm and 2-1/4 x 2-1/4), and various data forms were provided by Atmospherics Incorporated for assistance in plotting storms. Details of the procedure were the same as used previously (Schleusener and Henderson, 1962).

Operation of the equipment was on a general 24-hour alert basis. The system again proved very reliable. There was no off-the-air time logged due to equipment failure and only three cases of line power failure were noted. Total time on-the-air during the summer program was 460 hours.

Results

Tables 1, 2 and 3 give a summary of the radar climatology of hailstorms for 1963, and comparative data for 1961 and 1962.

From Table 1 it may be noted that the total number of echoes tracked in 1963 was approximately the same as in 1961, but less than the total number for 1962. As will be shown in the third part of this report, this is in general agreement with the amount of crop-hail damage in the area, as determined from records of loss to sugar beets obtained from the Great Western Sugar Company.

Table 2 shows that the number of storm days with hail in 1963 was less than for the preceding 2 years, while the number of echoes which were known to have produced hail on the ground in 1963 were not greatly different from 1961 and 1962. This apparent discrepancy is probably due to an improved verification system for determining hail occurrences for the years 1962 and 1963.

Table 3 summarizes the origin and movement of echoes identified as producing hail on the ground.

The greatest anomaly appears to be the number of echoes originating in Colorado and moving to Nebraska in 1962. Comparison of the tracks of hail-producing echoes (Figures 6 to 15 in Schleusener and Henderson 1962, and Figures 1 to 5 in this report) shows that a greater number of storms moved from the southwest in 1962 than in 1961 or 1963. Since 1962 was a year of substantially higher hail occurrence than either 1961 or 1963, it appears that movement from the southwest is characteristic of years of high hail frequency.

TABLE 1. SUMMARY OF PPI RADAR OPERATIONS - NEW RAYMER

(15 MAY - 31 JULY 1963)

				RADAR SCOPE PHOTOGRAPHY					
			NUMBER OF		STILLS		:	TIME-LAPSE	
	TIME-MST		ECHOES		TIME-MST			TIME-MST	
DATE	ON	OFF	CATALOGED	NUMBER	FIRST	LAST	BEGIN	END	FRAMES
5/15	1120	1710	8	10	1130	1620		NONE	
5/16	1325	1730	9	17	1335	1550		NONE	
5/23	1345	1630	7		NONE		1400	1700	2160
5/24	1215	1710	16	13	1220	1705	1215	1725	3660
5/25	1235	1415	7		NONE		1221	1315	648
5/26	1510	1830	8		NONE		1512	1815	2048
5/28	1400	2200	14		NONE			NONE	
5/29	1230	1845	17	9	1410	1815	1337	1835	3240
5/30	1320	1930	17	16	1320	1920	1335	1745	3000
5/31	1350	1745	14	4	1437	1734	1400	1735	1680
6/3	1245	1700	11	7	1302	1630	1254	1654	2880
6/4	1245	2100	2			NONE		NONE	
6/7	1400	2030	6			NONE		NONE	
6/8	1200	1745	15	10	1330	1725	1330	1730	2880
6/9	1500	1730	6			NONE		NONE	
6/11	1500	1700	6			NONE		NONE	
6/14	1415	1945	20	9	1440	1900	1435	1930	3084
6/15	1215	1830	15	14	1410	1915	1355	1832	3132
6/18	1015	1530	4	14		NONE		NONE	
6/21	1315	1800	7	7	1350	1651		NONE	
6/23	1430	2300	1	8	1520	1820		NONE	
6/26	1330	1615	8	4	1400	1540	1400	1605	1500
6/27	1430	1700	3	5	1510	1630	1509	1645	1152
6/28	1330	1545	2			NONE		NONE	
7/3	1230	1645	3	6	1245	1525	1245	1610	2400
7/5	1300	1730	17	10	1310	1652	1305	1640	2500
7/6	1700	2130	12	5	1735	2040		NONE	
7/8	1430	1800	9	6	1458	1745	1520	1750	1800
7/9	1115	1800	18	9	1255	1945	1250	1730	3240
7/11	1015	1700	15	23	1245	1740	1240	1747	3648
7/12	1315	1945	16	12	1412	1940	1335	1938	4000
7/14	1305	1600	14			NONE		NONE	
7/15	1615	1905	6			NONE		NONE	
7/16	1115	1800	17	18	1145	1700		NONE	
7/17	1345	1915	16	6	1900	1910	1340	1945	4000
7/18	1430	1700	6	4	1447	1635	1450	1637	1284
7/20	1215	2045	12			NONE		NONE	
7/22	1315	2130	14	9	1416	2010	1400	2100	3280
7/23	1445	1930	7	9	1655	1811	1529	1920	2772
7/24	1300	2015	37	6	1330	1819	1315	2000	3540
7/25	1200	1700	16			NONE	1304	1721	3084
7/26	1430	2000	10	4	1552	1855	1440	1940	1000
7/27	1430	1700	4			NONE		NONE	
7/28	1400	1500	9	1	1435	1435		NONE	
7/29	1315	1630	7			NONE		NONE	
7/31	1600	2030	10	28	1640	1900	1640	2020	2640
TOTALS		(1963)	498	289					70288
		(1962)	752	329					105680
		(1961)	504	99					36400

TABLE 2. THUNDERSTORM DAYS AND DAYS WITH HAIL WITHIN RANGE OF THE PPI RADAR SYSTEM AT NEW RAYMER, COLORADO

PERIOD	STORM DAYS WITH HAIL	STORM DAYS WITHOUT HAIL	TOTAL	TOTAL ECHOES CATALOGED	NUMBER OF ECHOES WHICH WERE KNOWN TO HAVE PRODUCED HAIL ON GROUND
			1963		
15-31 May	9	1	10	117	32
1-15 June	8	0	8	81	42
16-30 June	3	3	6	25	8
1-15 July	6	3	9	110	30
16-31 July	11	2	13	165	43
TOTAL	37	9	46	498	155
			1962		
15-31 May	11	6	17	140	34
1-15 June	9	6	15	186	37
16-30 June	10	4	14	194	55
1-15 July	11	4	15	106	28
16-31 July	11	3	14	126	29
TOTAL	52	23	75	752	183
			1961		
15-31 May	10	2	12	98	26
1-15 June	13	0	13	124	42
16-30 June	7	2	9	79	21
1-15 July	8	4	12	104	43
16-31 July	9	2	11	99	17
TOTAL	47	10	57	504	149

TABLE 3. ORIGIN AND MOVEMENT OF ECHOES IDENTIFIED AS PRODUCING HAIL ON THE GROUND

- ECHOES MOVED TO -

ECHOES ORIGINATED IN	COLORADO			KANSAS			NEBRASKA			WYOMING		
	1961	1962	1963	1961	1962	1963	1961	1962	1963	1961	1962	1963
COLORADO	56	67	84	12	5	5	21	52	22	3	8	1
KANSAS	0	0	0	7	1	3	0	3	2	0	0	0
NEBRASKA	12	1	2	6	1	0	11	19	12	0	0	1
WYOMING	13	7	2	0	0	0	7	14	16	1	5	6

TOTAL ECHOES IDENTIFIED AS PRODUCING HAIL ON THE GROUND	1961	1962	1963
	149	183	155

Figures 1-5 show the first echoes and subsequent tracks of precipitation cells identified as hail-bearing at some stage in their life cycle for each half-month period from 15 May-31 July 1963. In comparing 1963 with previous years (see Figures 6 to 15 in Schleusener and Henderson 1962) two features are dominant. The first is the smaller number of echoes for 1963 as compared to previous years, and the second, as noted above, is a greater tendency for motion from the southwest for 1962, a year of high hail frequency.

Figures 4 and 5 show that in July only a few echoes moved from the northwest quadrant, in contrast to previous years. As discussed in the last section of this report, this is a departure from the normal pattern followed in previous years, and is associated with a mean direction at 500 mb from the southwest quadrant for July 1963.

Figure 6 shows the initial locations of echoes which later produced hail for the period 15 May-31 July 1963. As in 1961 and 1962, no pattern is evident.

Forecast aid for forecasting thunderstorm occurrence and intensity in northeastern Colorado

A study was made to attempt to derive an objective forecast aid for forecasting the occurrence and intensity of thunderstorms in northeastern Colorado on non-frontal days. In this study, days with a low pressure center moving south of the study area through Alamosa or Amarillo were excluded, since they were considered easier to forecast than the non-frontal thunderstorms which had been found previously (Hodges 1959) to occur more frequently.

A "thunderstorm day" was defined as a day on which one or more radar echoes were observed (Schleusener and Henderson 1962, Schleusener and Henderson 1961) in northeastern Colorado. In addition, the intensity of thunderstorms was categorized by the number of echoes reported each thunderstorm day.

In addition to the references noted previously, data were obtained for the study from the Daily Weather Maps and from the National Climatological Summary.

Data were obtained for all "thunderstorm days" in 1961 and 1962. The parameters which were selected for use in the study are defined as follows:

Dew point change(deg. F.): the 24-hour change in surface dew point at Denver ending 00Z on the thunderstorm day.

Sea level pressure (millibars): the sea level pressure at Denver at 06 Z of the thunderstorm day.

Pressure gradient sum (millibars): the absolute value of the difference in sea-level pressure between Denver and Pueblo added to the absolute value of the difference in sea-level pressure between Denver and Goodland, taken at 06Z of the thunderstorm day.

Change in pressure gradient sum (millibars): the 24-hour change in the pressure gradient sum ending 06Z of the thunderstorm day.

Wind direction at Grand Junction (degree): the 500 mb wind direction at Grand Junction at 06Z of the thunderstorm day.

Dependent data from 1961 and 1962 were used to derive the forecast aid outlined below. Independent data from 1963 were used to test the results.

The procedure for use of the forecast aid is as follows:

1. Statement of the problem: Given that today is a "storm day", what will be its intensity?

2. Procedure:

a. Determine the numerical value of each of the five parameters listed above.

b. From Table 4, determine the index number associated with the numerical value of each parameter.

c. Determine the sum of the index numbers for all five parameters, and from the following table determine a forecast of intensity of thunderstorm activity.

Sum of index number	Forecast	
	Number of echoes	Intensity classification
< 30	none	none
30 - 39	< 7	weak
40 - 49	7 - 20	moderate
≥ 50	> 20	intense

Verification: Verification of this procedure was accomplished by using (independent) data from 1963. Days for verification were selected if one or more radar echoes were observed in northeastern Colorado east of the Continental Divide within a radius of 70 statute miles of Denver. The results are given in Table 5.

TABLE 4. INDEX NUMBERS FOR PROBABILITY OF OCCURRENCE OF THUNDERSTORMS FOR VARIOUS NUMERICAL VALUE OF SYNOPTIC PARAMETERS, BASED ON 1961 AND 1962 DATA

Dew Point Change (Deg F)	
plus 7 and greater	12
plus 5 to 6	3
plus 4	6
minus 1 to plus 3	9
minus 2 to minus 3	6
minus 4	12
minus 5	8
minus 6 to minus 7	3
less than minus 7	8

Change in Pressure Gradient Sum (mb)		
plus 6 and greater		1
plus 3 to 5.9		3
plus 1 to 2.9		7
minus 0.9 to plus 0.9	13	13
minus 1.9 to minus 1		7
minus 4.9 to minus 2		5
minus 5.9 to minus 5		2
minus 6 or less		1

Sea Level Pressure (mb)	
1000.0 to 1004.9	1
1005.0 to 1009.9	6
1010.0 to 1017.4	16
1017.5 to 1019.4	6
1019.5 to . . .	3

Pressure Gradient Sum (mb)	
0.0 to 0.9	3
1.0 to 1.4	15
1.5 to 1.9	5
2.0 to 2.4	8
2.5 to 3.4	5
3.5 to 4.4	8
4.5 to 4.9	6
5.0 to 5.9	4
6.0 to 6.9	1
greater than 7.0	5

500 mb Wind Direction at Grand Junction (Degrees)	
160 - 209	6
210 - 249	15
250 - 289	2
290 - 309	9
310 - 159	2

TABLE 5. VERIFICATION OF FORECAST AID, BASED ON (INDEPENDENT) 1963 DATA

		OBSERVED				
		NO	WEAK	MODERATE	INTENSE	TOTAL
FORECAST	NO	-	1	3	-	4
	WEAK	-	1	2	-	3
	MODERATE	-	4	11	1	16
	INTENSE	-	1	4	-	5
	TOTAL	0	7	20	1	28

Verification by category

Classification	Forecast	Observed	Per Cent Correct
NO	4	0	0
WEAK	3	1	33
MODERATE	16	11	69
INTENSE	5	0	0
ALL	28	12	43

Verification by considering forecast verified when within plus or minus one category

NO	4	1	25
WEAK	3	3	100
MODERATE	16	16	100
INTENSE	5	4	80
ALL	28	24	86

General comments on genesis and movement of thunderstorms

Comments in this section are based on concurrent observations of genesis of thunderstorms and standard synoptic data. These comments are presented primarily as a point of departure for further study rather than as definitive conclusions.

Figure 7 was prepared to represent a generalized surface pressure pattern as of 0700 MST for non-frontal cases. (Figure 7 is a subjective estimate of the patterns prevailing.)

1. Natural drainage patterns caused by local terrain features tend to produce a drainage low in the vicinity of Denver.

2. Thunderstorms tend to form first in regions of greatest curvature of isobars, in zones marked A, B, and C.

3. Once developed, thunderstorms tend to move from their genesis position when surface isobar orientation is parallel to the 500 mb flow aloft. Conversely, thunderstorms which form along the mountains under the influence of the drainage low west of Denver will not move to the east if the isobars are not within $\pm$ 30 degrees of the same orientation as the 500-mb wind flow.

4. Thunderstorm genesis is favored at about 11 MST in the region marked a-a', and at about 14-15 MST, either northwest or southwest of Denver.

5. Thunderstorm genesis in zone A is favored by the advection of moist air into the zone from numerous nearby reservoirs.

The subjective estimate of pressure patterns as given in Figure 7 may be compared with the average maps presented in Figure 8. The maps in Figure 8 were prepared by averaging sea-level pressure, wind direction, and wind speed for 10 days of heavy thunderstorm activity, and for 10 days of no thunderstorm activity. The resulting average values of pressure, wind direction, and wind speed were used to draw the isobars of Figure 8. Both maps of Figure 8 show a similarity to the generalized case of Figure 7.

Although both maps of Figure 8 show this simularity to Figure 7, it may be noted that the average map for hail cases in Figure 8 has lower pressures (1011.0 vs 1015.8 mb for Denver) and a higher gradient sum (1.5 vs 0.6 mb).

Both of these factors indicate a higher probability of low-level convergence on the thunderstorm days associated with the lower pressure.

AVERAGE MONTHLY WINDS AND CROP-HAIL DAMAGE TO SUGAR BEETS

Records of hail damage to sugar beets in northeastern Colorado from the Great Western Sugar Company were examined in an attempt to identify periods of various degrees of hail intensity which could be compared with various indices of the general circulation. Table 6 gives a tabulation of total acres of beets planted, and hail damage statistics for the three factory districts of Great Western Sugar Company in northeastern Colorado for the period 1959-1963. Figure 9 shows a plot of monthly damage for the months of May, June and July, and illustrates the high variability of hail damage for successive months, as well as for successive years. It may be noted that damage for each year was lower in June than in May, and usually was higher in July than in June.

Average 500 mb winds for Denver for the months of May, June and July were determined for the years 1959-63 for a comparison with hail damage statistics. The average winds for 1959-62 were obtained from climatological data, and the winds for 1963 were obtained from the daily weather map. Table 7 shows the average monthly 500 mb winds for May, June, and July for 1959-63.

Table 7 shows that the average 500 mb wind direction changes from the southwest quadrant in May to the northwest quadrant in July. As noted previously, 1963 was an exception, and precipitation cell motion from the northwest was not a common feature in July 1963.

In Figure 10 values of monthly hail loss to beets (in percent of acres planted) are plotted at coordinates of mean monthly 500 mb wind direction and speed. No relationship is evident between hail damage and either wind speed or direction.

Despite this lack of relationship it was found that a change in mean monthly 500 mb wind speed is related to the monthly change in hail damage. Figure 11 shows the per cent change in damage from one month to the next or a function of change in mean monthly 500 mb wind speed during the same period, and shows a positive slope for the line giving the relationship for each year.

TABLE 6. TOTAL NUMBER OF ACRES OF SUGAR BEETS PLANTED AND DAMAGED IN OVID, FORT MORGAN, AND STERLING FACTORY DISTRICTS OF GREAT WESTERN SUGAR COMPANY, 1959-1963 (SOURCE: REPORTS OF DAMAGE FROM FACTORY MANAGERS)

Acres Planted			Hail Damage--all districts, all categories of damage		
Year	Factory District	Acres Planted	Month	Acres Damaged	Per Cent of Acres Planted
1959	Ovid	10,200	May	7,525	19
	Fort Morgan	22,073	June	3,447	8
	Sterling	8,200	July	6,056	15
	Total	40,473		17,028	43
1960	Ovid	10,857	May	14,336	33
	Fort Morgan	23,737	June	13,793	31
	Sterling	9,087	July	5,481	13
	Total	43,681		33,610	77
1961	Ovid	15,552	May	17,570	31
	Fort Morgan	29,025	June	5,491	10
	Sterling	11,013	July	13,208	24
	Total	55,590		36,269	65
1962	Ovid	17,016	May	31,833	54
	Fort Morgan	29,583	June	8,370	14
	Sterling	11,881	July	31,030	53
	Total				
1963	Ovid	18,069	May	10,425	17
	Fort Morgan	29,886	June	1,860	3
	Sterling	11,462	July	9,082	15
	Total	59,417		21,367	35

TABLE 7. AVERAGE MONTHLY 500 MB WIND SPEED (KNOTS) AND DIRECTION (DEGREES) FOR MAY-JULY, 1959-63, DENVER, COLORADO

Year	May	June	July
1959	248/25.1	267/13.6	309/17.3
1960	280/13.6	279/23.3	309/11.9
1961	261/17.5	304/14.4	303/16.1
1962	240/23.9	259/15.9	267/14.2
1963	255/29.2	235/23.2	236/19.2
Average	257/21.9	269/18.1	285/15.7

REFERENCES

Schleusener, R. A., and T. J. Henderson, 1962: Radar Climatology of Hail Storms In and Near Northeastern Colorado, 15 May-31 July 1962, With Comparative Data for 1961. Civil Engineering Report CER62RAS79, Colorado State University, Fort Collins, Colorado.

Hodges, Hayden, 1959: Synoptic Patterns Associated with Hail Occurrence in Northeastern Colorado. Civil Engineering Report CER59HH29, Colorado State University, Fort Collins, Colorado.

Schleusener, R. A., and T. J. Henderson, 1961: Hail Genesis Areas In and Near Northeastern Colorado. Civil Engineering Report CER61RAS58, Colorado State University, Fort Collins, Colorado.

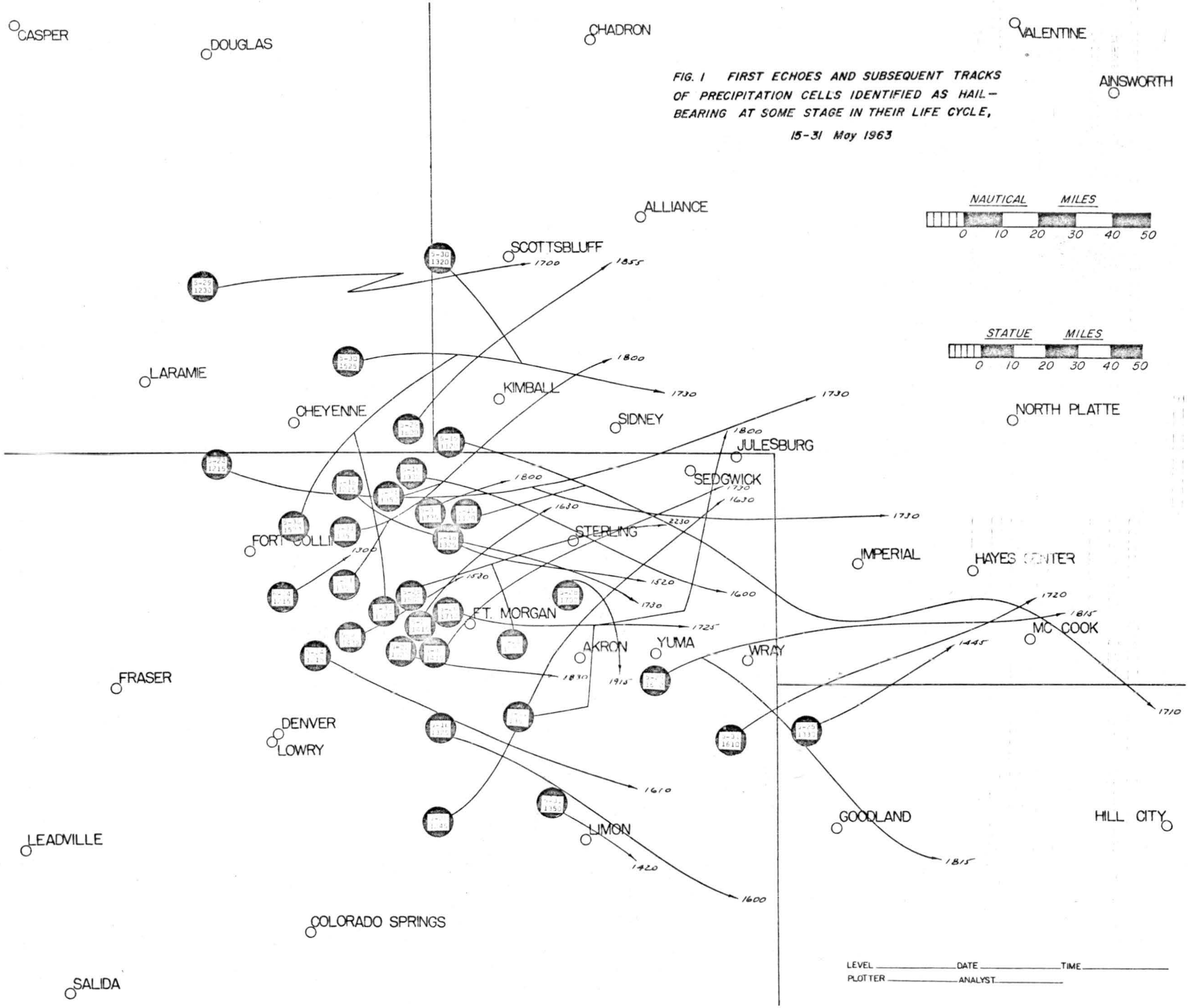


FIG. 1 FIRST ECHOES AND SUBSEQUENT TRACKS OF PRECIPITATION CELLS IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THEIR LIFE CYCLE, 15-31 May 1963

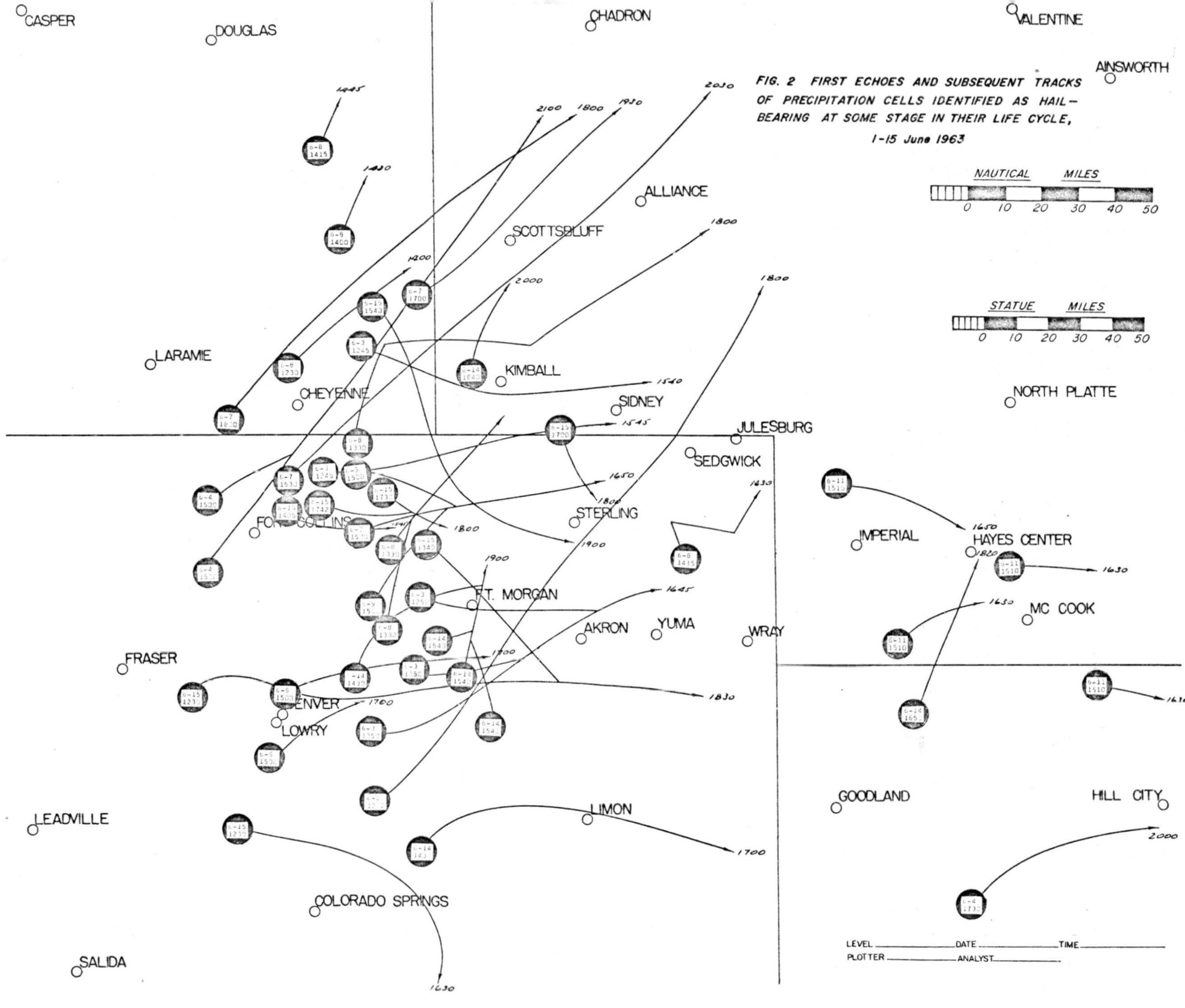


FIG. 2 FIRST ECHOES AND SUBSEQUENT TRACKS OF PRECIPITATION CELLS IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THEIR LIFE CYCLE, 1-15 June 1963

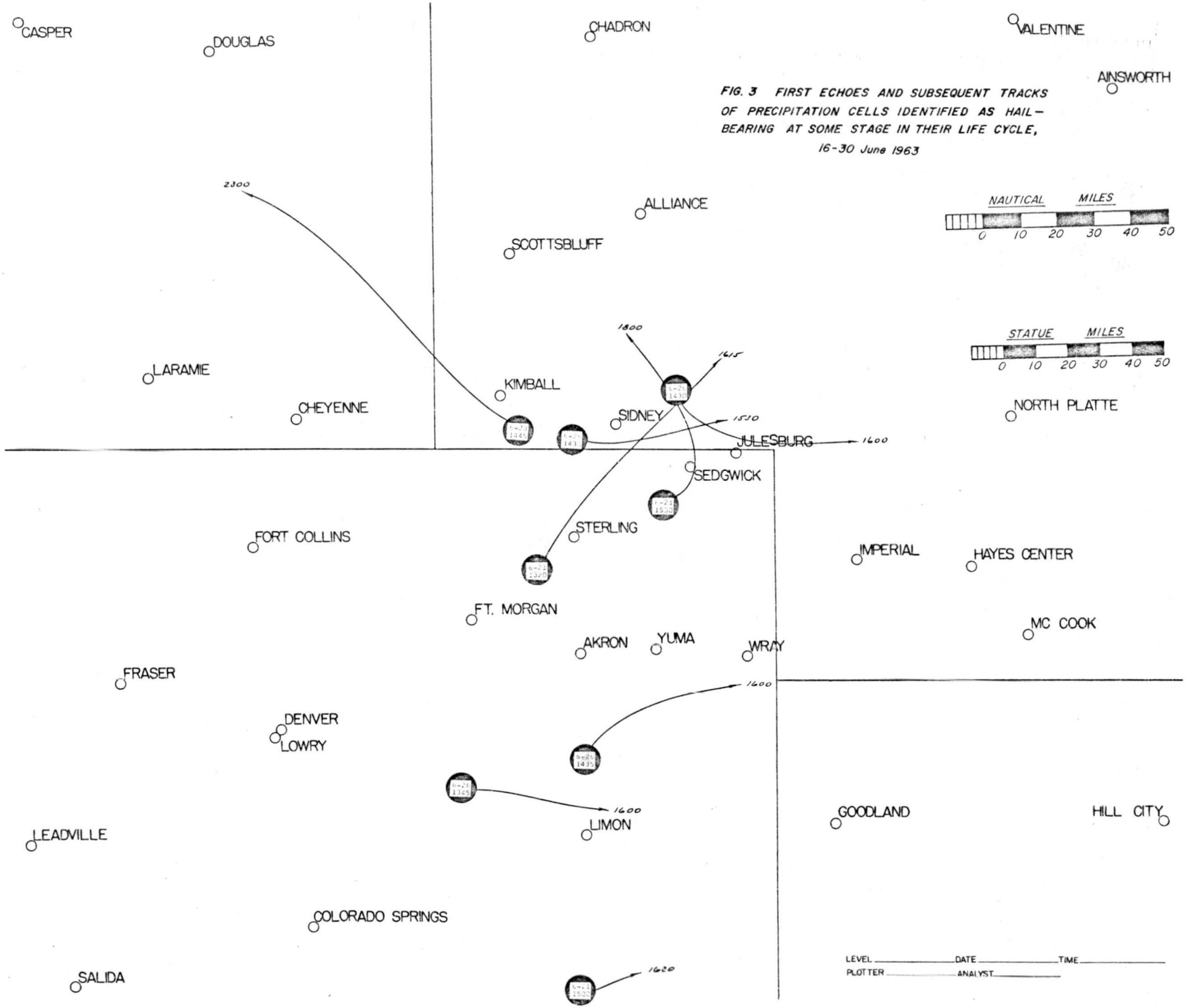


FIG. 3 FIRST ECHOES AND SUBSEQUENT TRACKS OF PRECIPITATION CELLS IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THEIR LIFE CYCLE, 16-30 June 1963

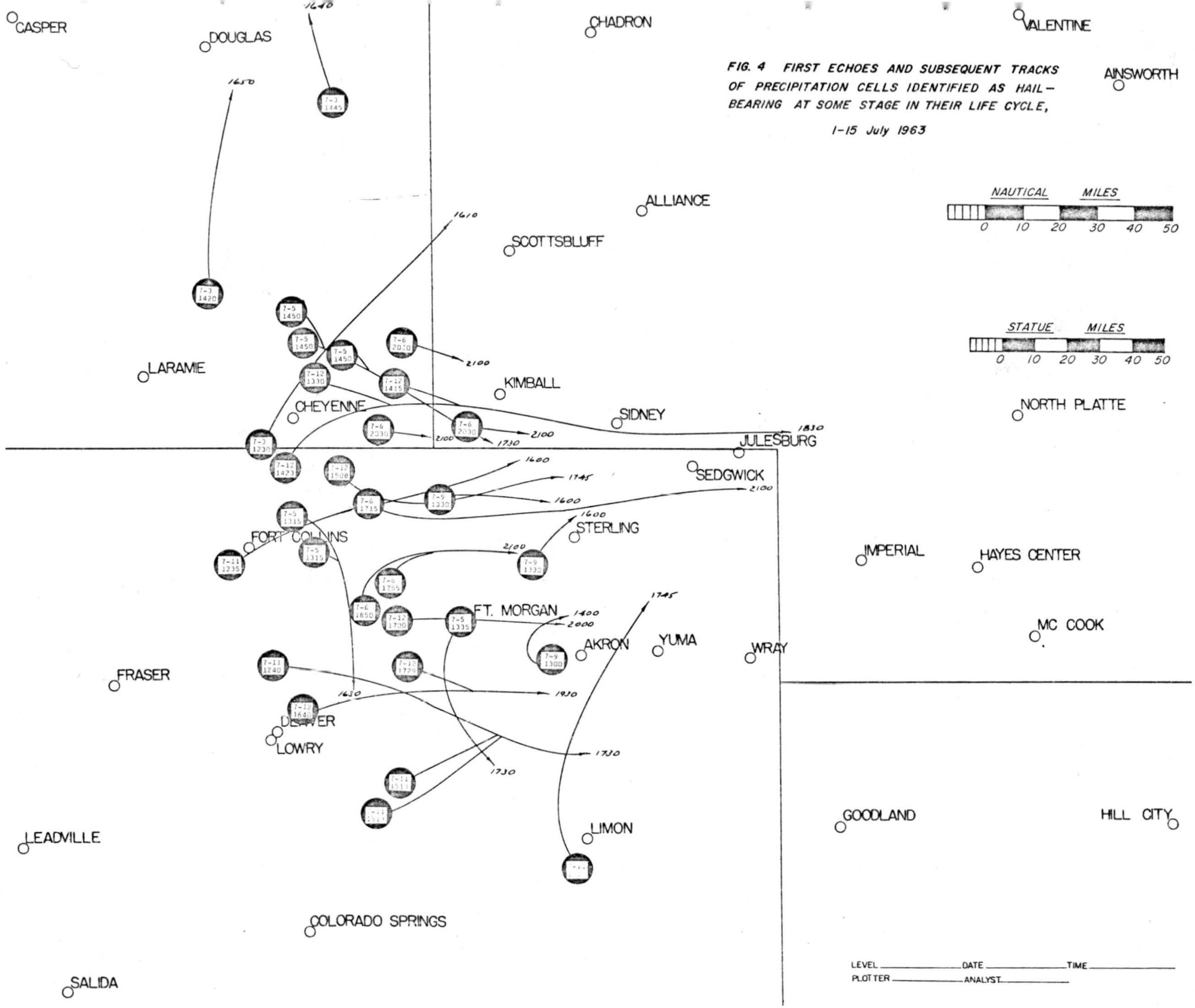


FIG. 4 FIRST ECHOES AND SUBSEQUENT TRACKS OF PRECIPITATION CELLS IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THEIR LIFE CYCLE, 1-15 July 1963

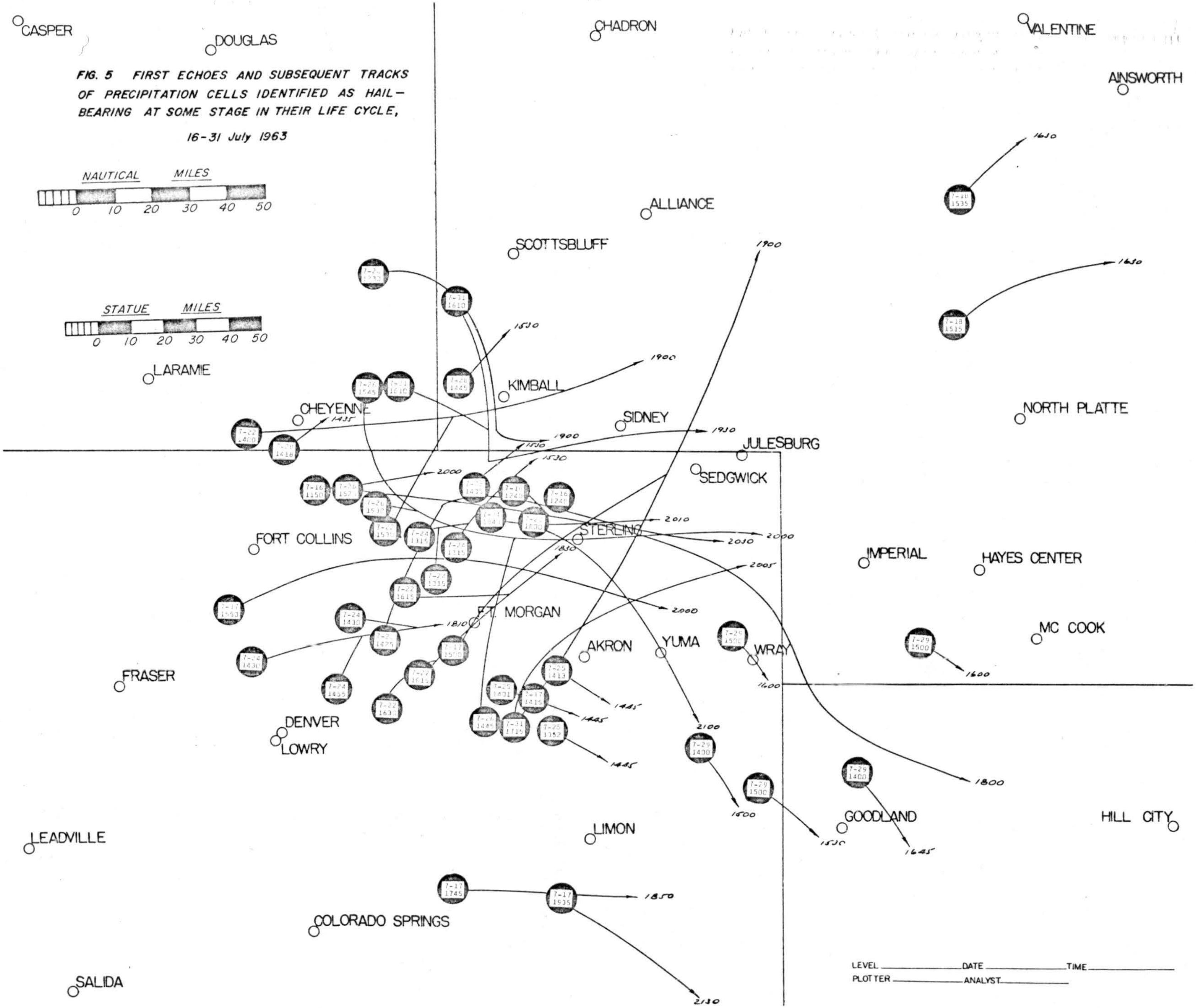


FIG. 5 FIRST ECHOES AND SUBSEQUENT TRACKS OF PRECIPITATION CELLS IDENTIFIED AS HAIL-BEARING AT SOME STAGE IN THEIR LIFE CYCLE,

16-31 July 1963

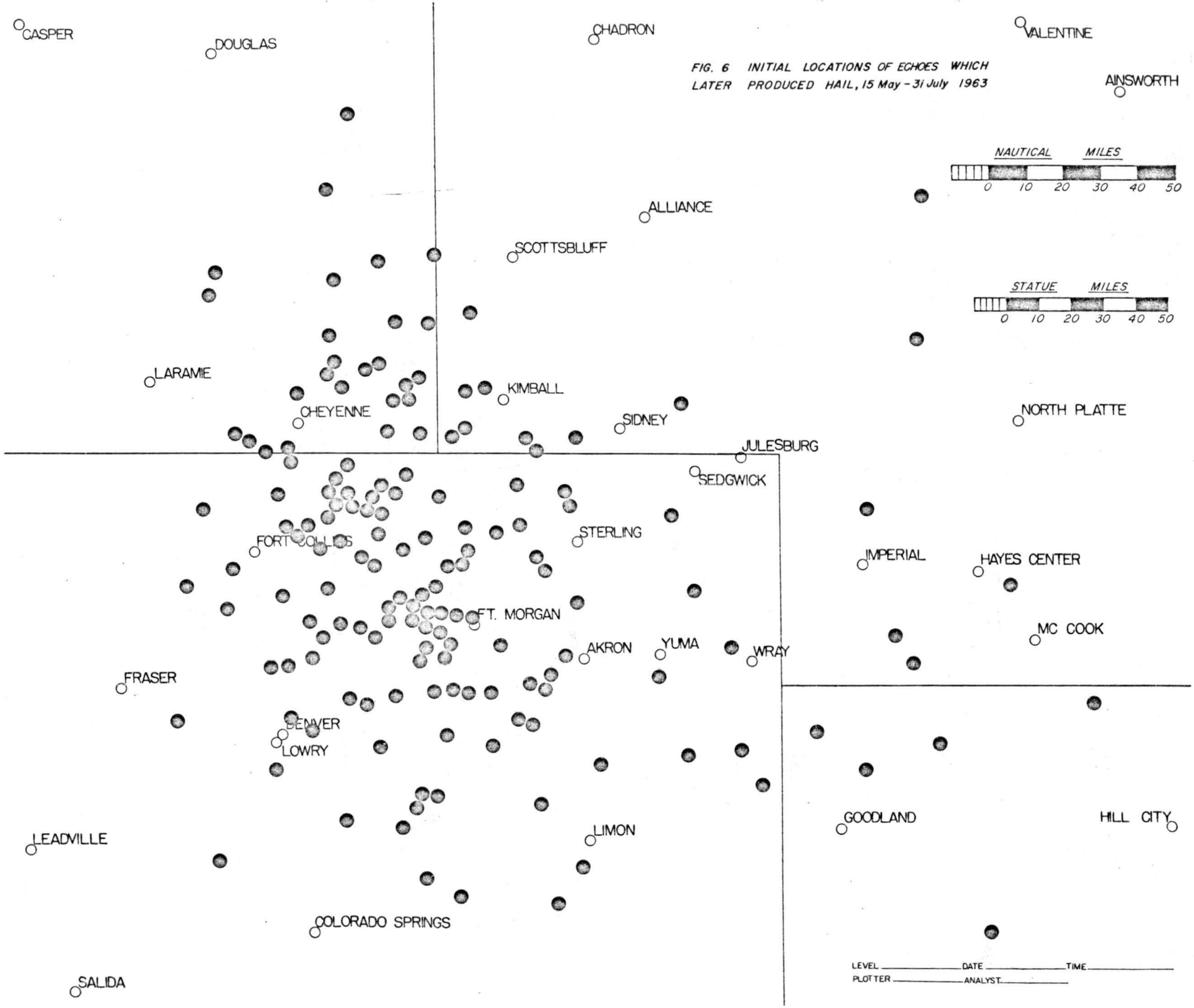
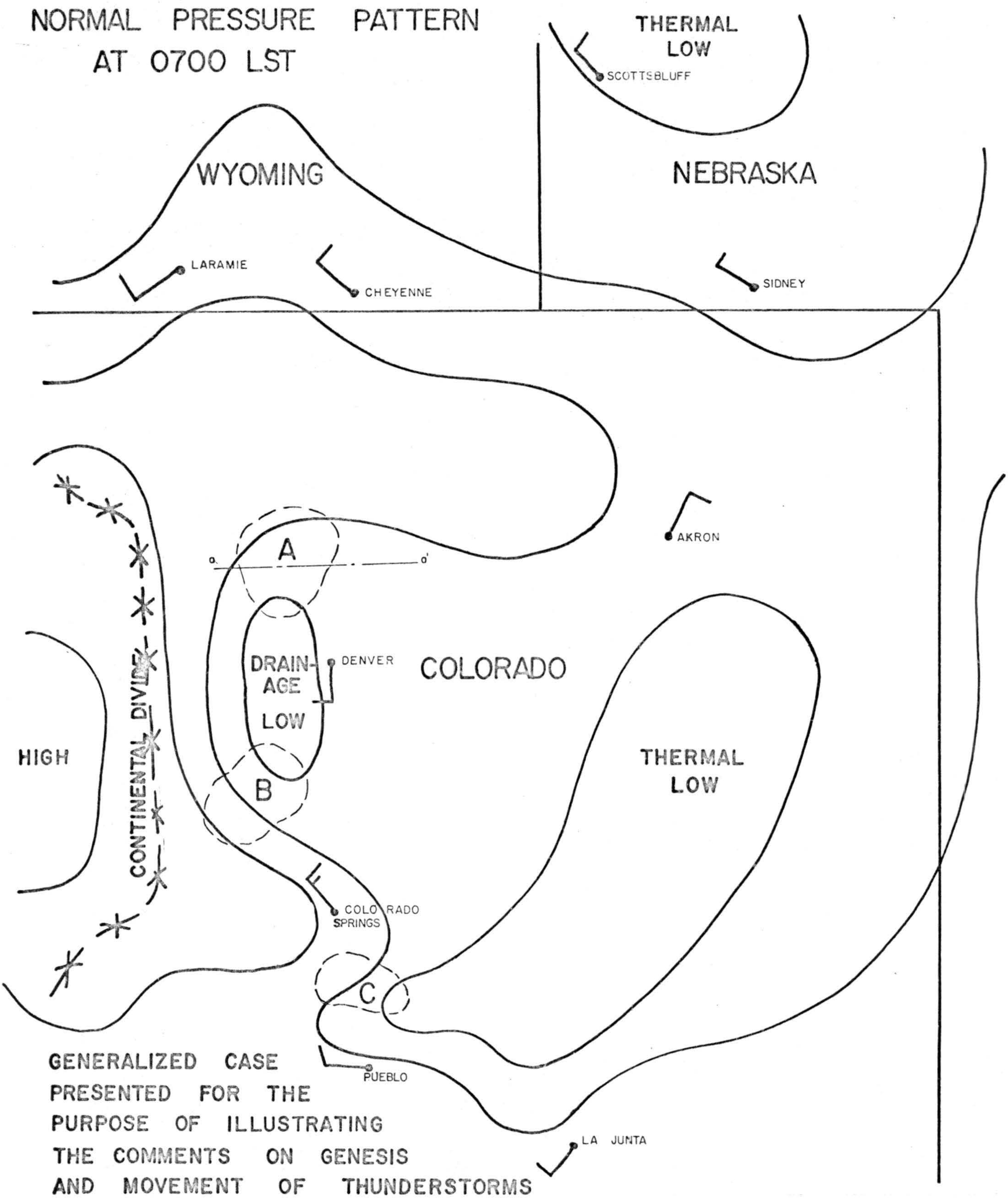


FIG. 6 INITIAL LOCATIONS OF ECHOES WHICH LATER PRODUCED HAIL, 15 May - 31 July 1963



NORMAL PRESSURE PATTERN
AT 0700 LST
THERMAL
LOW
SCOTTSBLUFF
WYOMING
NEBRASKA
LARAMIE
CHEYENNE
SIDNEY
AKRON
A
a
a'
DRAIN-
AGE
LOW
DENVER
COLORADO
HIGH
CONTINENTAL DIVIDE
THERMAL
LOW
B
COLORADO
SPRINGS
C
PUEBLO
LA JUNTA
GENERALIZED CASE
PRESENTED FOR THE
PURPOSE OF ILLUSTRATING
THE COMMENTS ON GENESIS
AND MOVEMENT OF THUNDERSTORMS

FIGURE 7

SURFACE PRESSURE PATTERNS

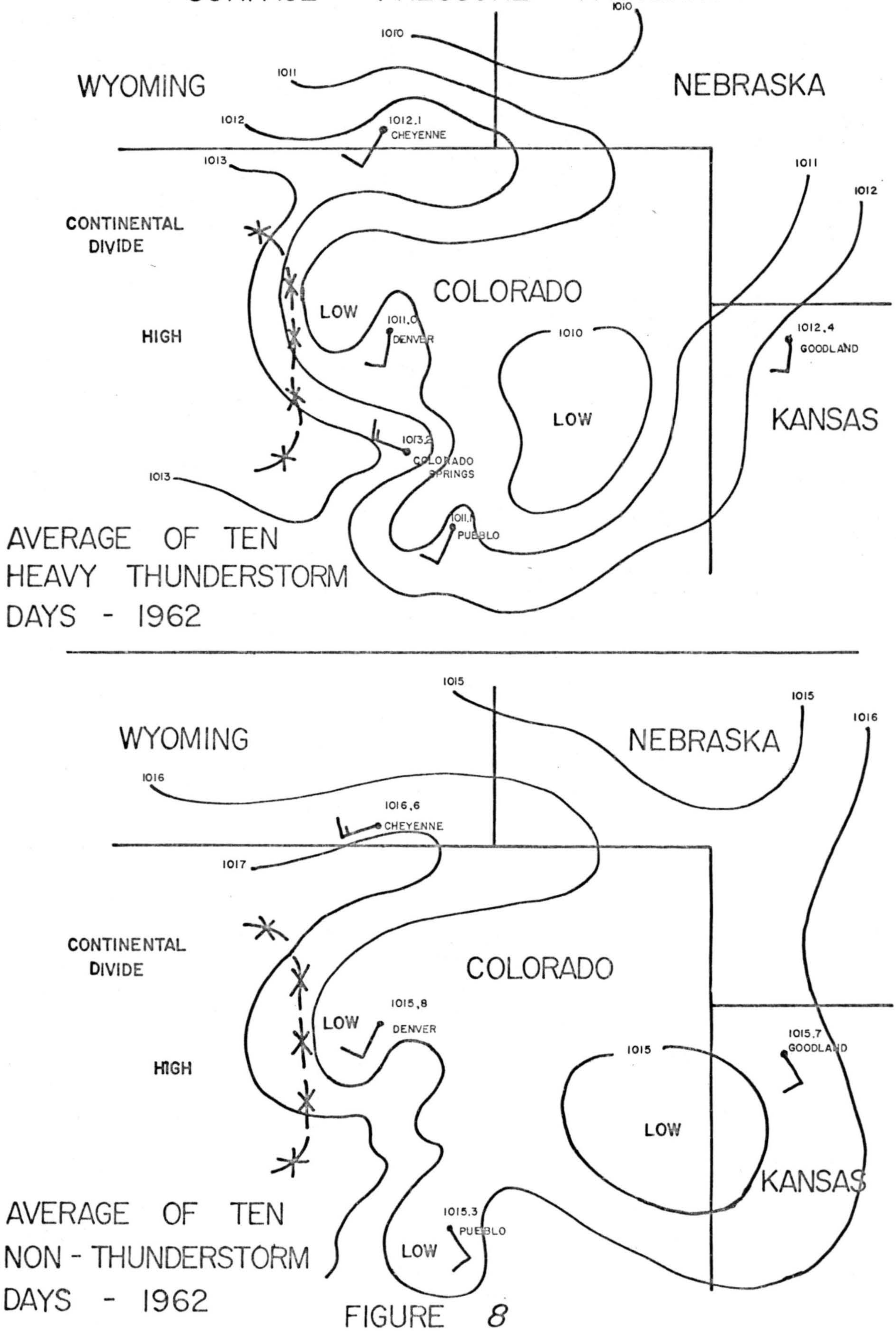


FIGURE 8

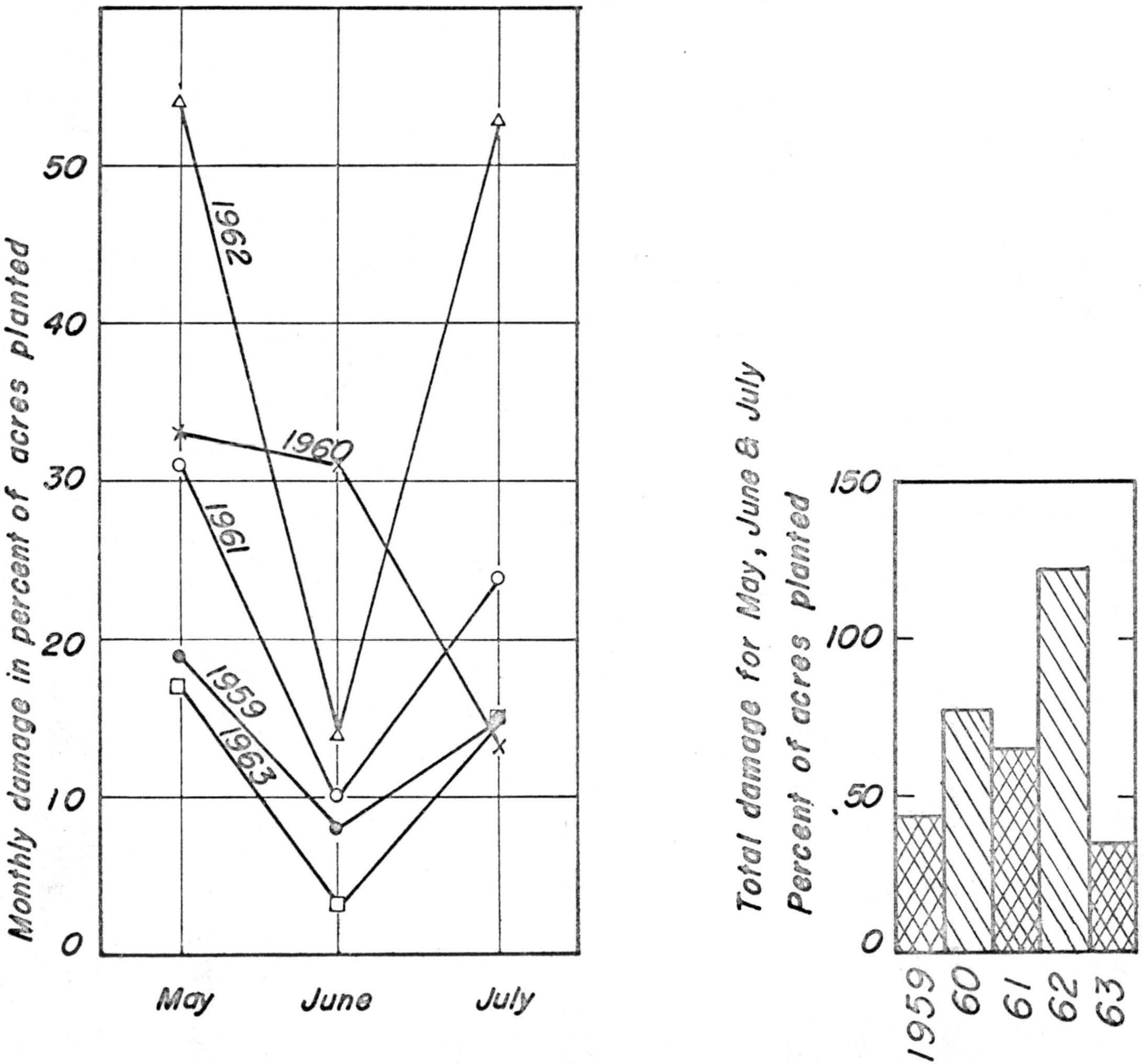


FIG. 9 HAIL DAMAGE TO SUGAR BEETS IN THE GREAT WESTERN FACTORY DISTRICTS OF OVID, FORT MORGAN AND STERLING, COLO. FOR ALL DAMAGE CATAGORIES, 1959—1963

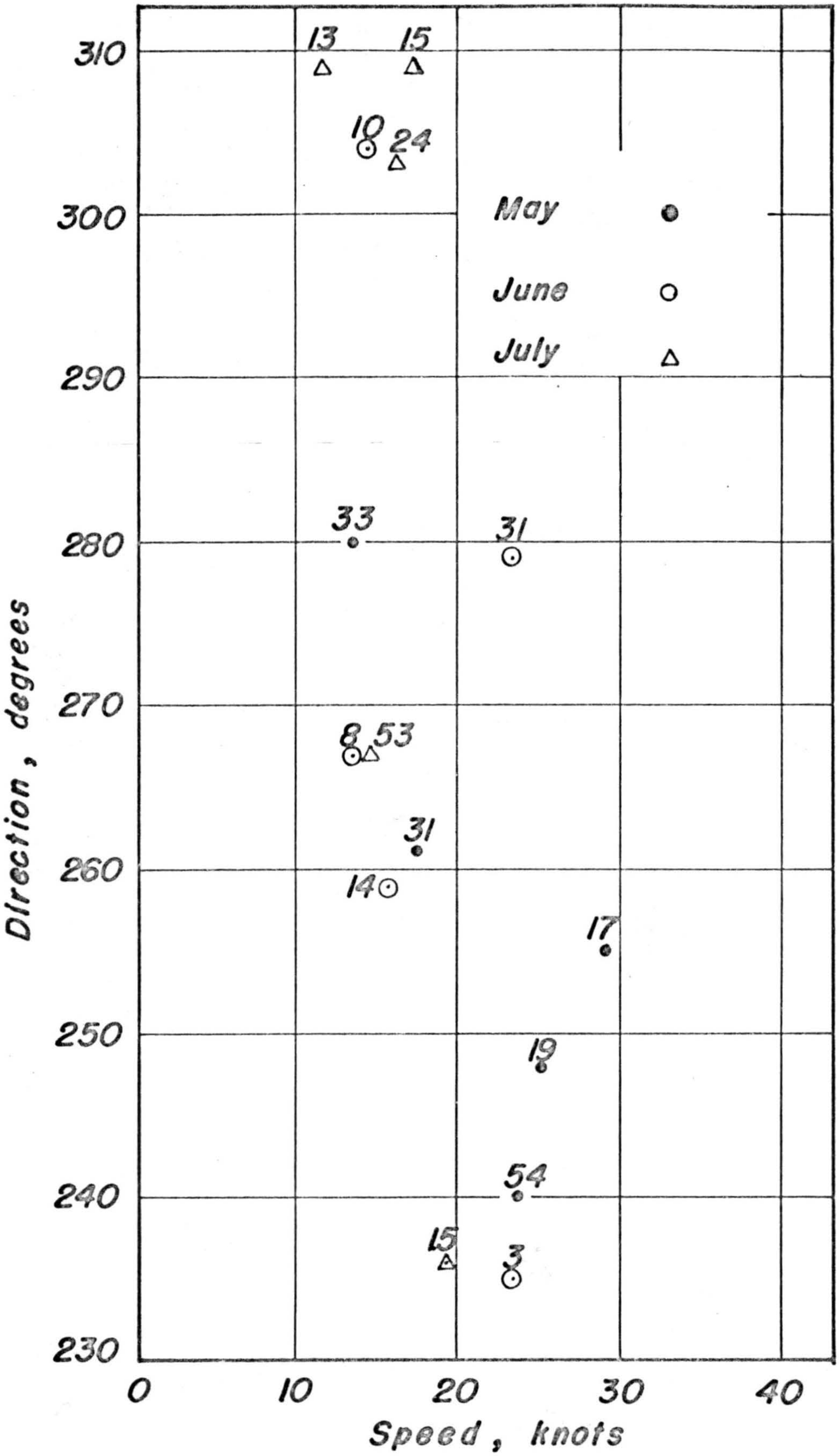


FIG. 10 MONTHLY VALUES OF PER CENT OF ACRES OF SUGAR BEETS DAMAGED, PLOTTED AT COORDINATES OF MEAN MONTHLY 500 MB WIND SPEED AND DIRECTION

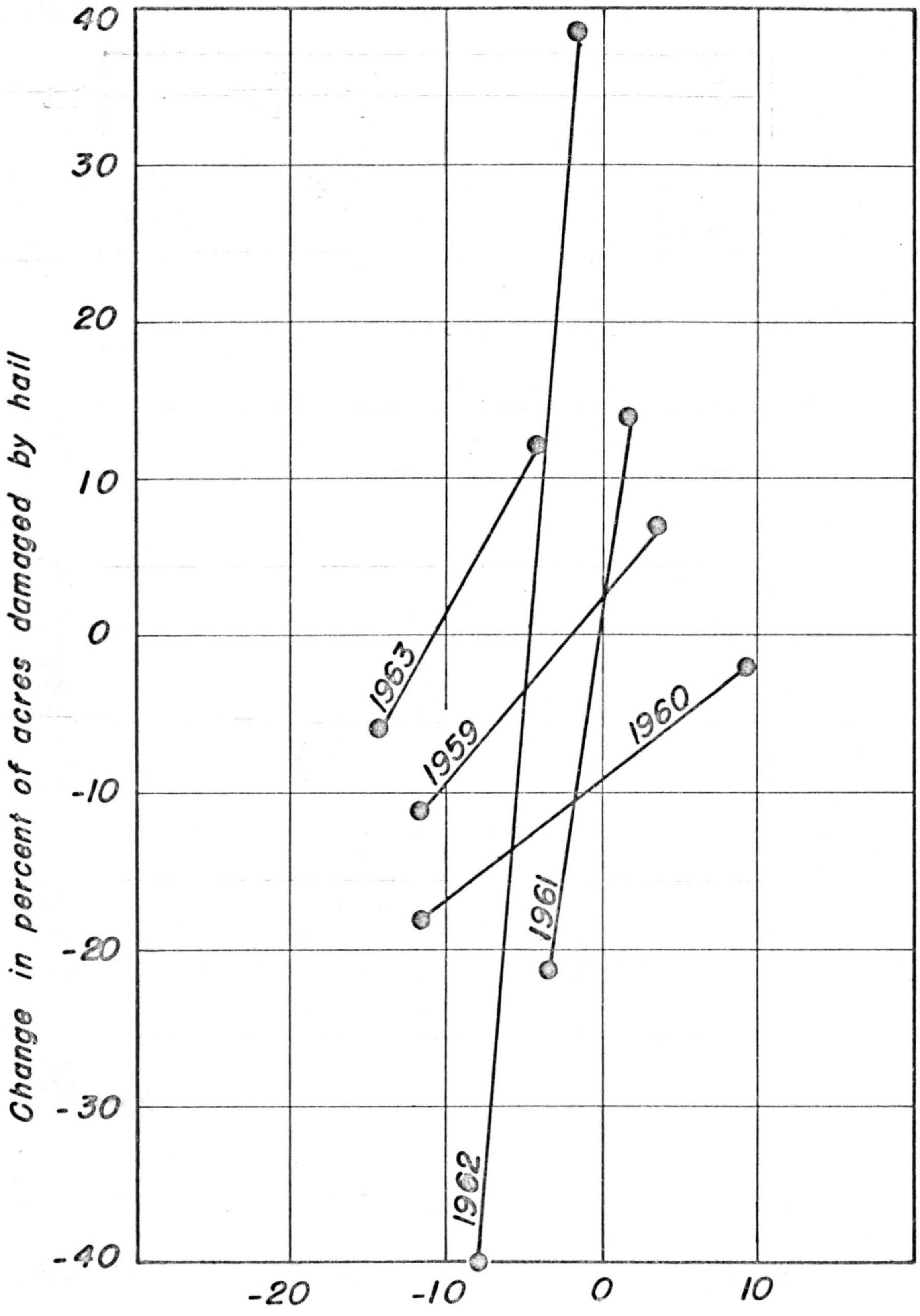


FIG. 11 PER CENT CHANGE IN HAIL DAMAGE FROM ONE MONTH TO THE NEXT AS A FUNCTION OF CHANGE IN MEAN 500 MB WIND SPEED DURING THE SAME PERIOD