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McGILL UNIVERSITY
STORMY WEATHER RESEARCH GROUP

SCIENTIFIC REPORT MW-36

Some Characteristics of Alberta Hailstorms

by

A. E. Carte

AUGUST, 1962

Dr. Carte of the National Physical Research Laboratory, South Africa, did the work reported here as a National Research Council Post-doctoral Fellow. He has since returned to Pretoria. The data had been secured by Alberta Hail Studies, a project supported by the Research Council of Alberta, the Canadian Meteorological Service and the National Research Council of Canada.

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Editor's Preface

This report gathers some notes prepared by the author in the course of his examination of the data accumulated by Alberta Hail Studies during the past six years. Dr. A. E. Carte of the South African Council of Scientific and Industrial Research has just completed a twelve-month stay with us as a N.R.C. Post-doctoral Fellow.

These notes form part of the series of studies by the Alberta Hail Project, all of which are listed below. If some of the present items are a bit shorter and less complete than the author wanted them to be, this must be ascribed to the shortage of time Dr. Carte had available; within the year mentioned he spent several months in the field and for some time was concerned with problems related to hailstone collection and study, on which he has already written in Scientific Report MW-35. These items nevertheless contribute additional building blocks for the construction of the complete theory of the hailstorm.

August, 1962 Walter Hitschfeld

Scientific Report MW-27 Studies of Alberta Hailstorms, 1957
R. H. Douglas and Walter Hitschfeld

Scientific Report MW-30 Alberta Hail 1958 and Related Studies
Parts I and II by R. H. Douglas
Part III by R. H. D. Barklie and N. R. Gokhale

Scientific Report MW-34 Interim Account of Hail Studies, November, 1960
R. H. Douglas, J. S. Marshall and R. H. D. Barklie

Scientific Report MW-35 Alberta Hail Studies, 1961. Nine contributions by:
A. E. Carte, R. H. Douglas, C. East, K. L. S. Gunn, Walter Hitschfeld, J. S. Marshall, E. J. Stansbury

Table 1

Number of Hail Reports

Year	b	c	B	C_e	C_e/C
1960	88	2860	191	6207	29%
1961	19	604	196	6230	29%

b, number of reports of hailfall by farmers with hail baskets,

c, number of reports received from farmers without hail baskets,

B, number of hail baskets in field,

C_e, number of active hail reporters,

C, number of potential hail reporters; i.e. of addresses to which cards were sent; this was 21,000,

C_e/C, ratio of active to potential hail reporters.

SOME CHARACTERISTICS OF ALBERTA HAILSTORMS

1. DENSITY OF HAIL REPORTING NETWORK (1960, 1961)

As reported on previous occasions (e.g. in the Scientific Reports mentioned in the Preface) reports of hailfall have been solicited from farmers in central Alberta since the summer of 1956. In 1960 and 1961 the area of the project was 20,000 square miles, and requests for reports were mailed to 21,000 householders. In addition some 200 farmers, distributed uniformly over most of the area, were supplied with hail-collecting baskets. It was possible to establish personal contact with these people, who agreed to collect hail samples and to report all occurrences of hail.

In studies of this kind, it is to be expected that many of those who only received cards in the mail would ignore them and not send in hail reports. This was borne out by the returns for the two years which showed that proportionally many more basket-holders reported hail than those who had cards only. The effective number of hail-reporters C_e (i.e. the number of farmers who would return a card to us whenever they noticed hail) may be estimated from the returns if one assumes that all occurrences of hail at basket locations were reported and that these baskets were not located in preferred hail areas. If the number of occurrences of hail reported by the C people who had been asked to report is c, and the number reported by B basket-holders is b, then, presumably, $b/B = c/C_e$. Results given in Table 1 indicate that about 30% of those who received cards and had hail, have reported it. This gives the observer net an effective average density of 30 observers per 100 square miles during 1960 and 1961. The project area was slightly smaller in earlier years but correspondingly fewer cards were sent out so that the network density may be taken to be the same as for 1960 and 1961.

Table 2

Hail at basket locations in 1960

Number of hailstorms reported	Number of stations reporting	Expected number of reporting stations
1	48	-
2	15	12
3	2	3
4	1	1

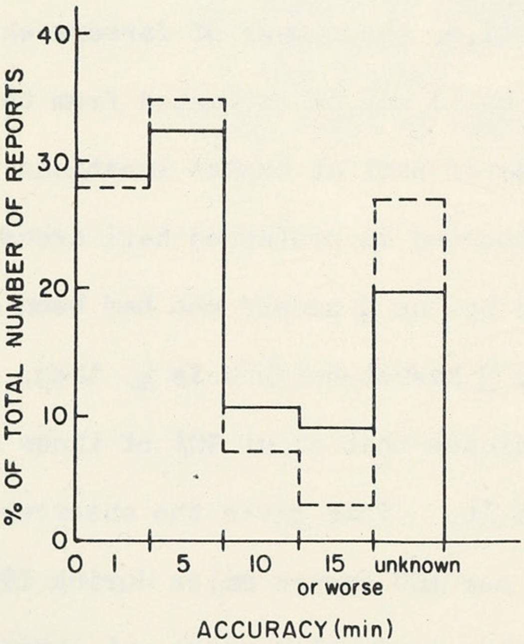

Fig. 1: Reported accuracy of starting time of hailfalls during 1960.
___ based on 2627 card reports
- - based on 71 reports from hail-collecting stations.

The effective network density of 30 per 100 square miles depends upon our assumption that all occurrences of hail at basket locations were in fact reported. This was probably so, at least in 1960 when there were sufficient reports from basket locations to check on whether observers who reported several storms were more reliable than those who reported fewer. The data suggest that the probability of any one station having received hail once is $P_1 = 48/191$ (see Table 2); hence the number of stations which should have received hail twice, may be expected to be $P_2 = \left(\frac{48}{191}\right)^2$. Using such considerations, the last column of Table 2 was prepared. The close agreement between these computed numbers and those actually observed indicates that those who reported more than one hailstorm during the season were probably no more reliable than the other basket holders. It is a slight extension to suppose that the basket holders reported all hailfalls.

Observers were asked to report the location, time and duration of hail, and the size of the largest hailstones. Unfortunately, the reported times are often unreliable, there being a strong bias towards reporting the time of commencement of hail on the quarter, half or whole hours (see Douglas, Report MW-35). In 1960 and 1961, observers were asked to state the accuracy of their times. A histogram of the reported accuracies in 1960 is shown in Fig. 1. It will be seen that 60% of the times are claimed to be correct to within five minutes. Such a distribution may reasonably be assumed to apply to earlier years.

Hail "Point" Frequency

In 1960, 88 hail reports were received from the 191 basket locations. On the assumption that the people looking after these hail baskets are completely reliable, reporting all hail they saw (not just the samples they collected), this gives us an average point frequency for this year of 88/191 = 0.46.

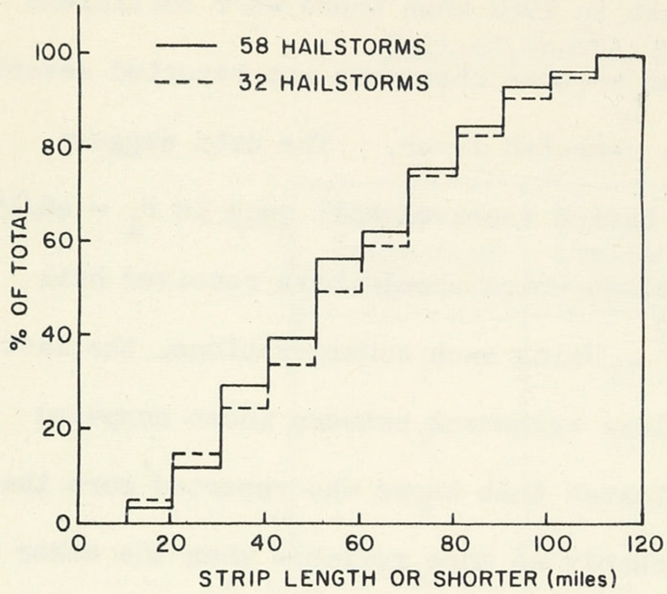

Fig. 2: Cumulative distribution of the length of swaths covered by hailstorms (1957-1961). The dashed lines, for 32 storms, are taken from Hitschfeld and Douglas, Report MW-35.

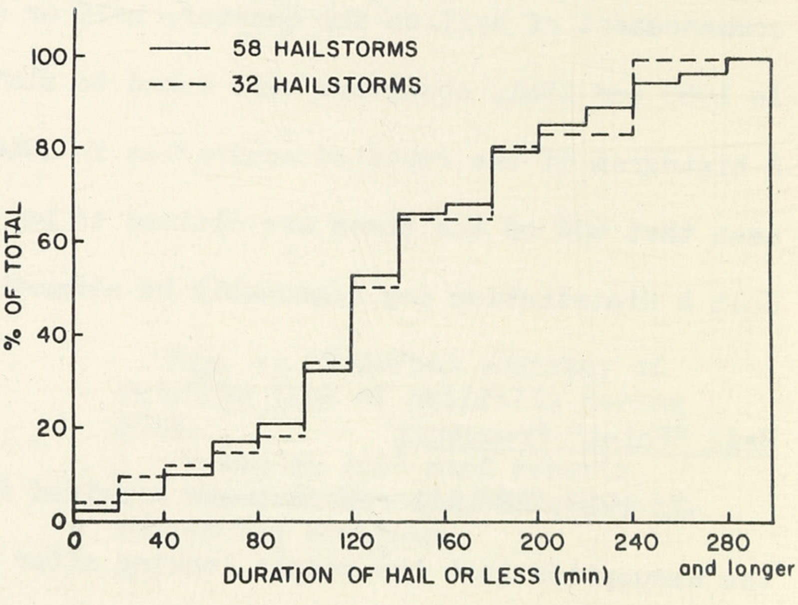

Fig. 3: Cumulative distribution of the times during which hail fell from given storms (1957-1961). The dashed line, for 32 storms, is taken from Hitschfeld and Douglas, Report MW-35.

On the other hand Thompson (1956) reports an average yearly point frequency of 3.5 for the years 1950-1954, based on observations in Edmonton, Lethbridge and Calgary. Since the year 1960 was described by Thompson (1960) as the worst for hail since 1953 the difference between his value of 3.5 and ours of 0.46 is remarkable. Though the possibility that some of our observers missed some of the hail cannot be discounted, other explanations for the great discrepancy are available. Thompson's figures are based only on three regions in Alberta and may thus be afflicted with a large sampling error. To a greater extent, the discrepancy may be due to an ambiguity in the concept of "point frequency" since this involves the area surveyed by the observer. Our 191 observers surely do not inspect equal or carefully defined areas, but we believe that they would confine their attention to one or a few thousand square feet. Thompson on the other hand suspects that in some cases at least his hail occasions may signify hailfall anywhere within his large city areas.

2. HAIL SWATHS

Hitschfeld and Douglas in Report MW-35 described the essentials of a theory of hail development based on the concept of a steady hail machine. The evidence for such a mechanism includes the frequently remarkable steadiness of the maximum height of the radar echoes, first pointed out in Report MW-27. The above authors added further evidence in the form of histograms of the length and duration of hailfalls measured in 32 storms from the years 1957-1959. Figures 2 and 3 are up-dated versions of such analyses comprising now 58 storms and including the years 1960 and 1961. It will be seen for instance that in half the cases the hail swaths were more than 50 miles in length and lasted longer than two hours. While, in the theoretical study referred to, the concept of the "steady state" was used as a working hypothesis, the findings represented in Figs. 2 and 3 must not be construed to mean that the hailstorms did move at

Table 3

Date of Storm	Hail Swath Length (Miles)	Number of reports	Duration of hail (min)	Average Duration of hail at a point (min)	Velocity of hail cell		Reports of rain before hail	Reports of large before small hail		Diameter of largest hail (cm)	Diameter of most commonly reported maximum hail size (cm)
					Speed (m.p.h.)	Bearing of origin (deg)	%	No	%		
July 26, 1957 (I)	80	205	150	12	30	235	9	9	90	>5	3-5
(II)	80	90	150	11	30	230				>5	2-3
June 13, 1959	90	133	145	11	40	260	23	-		3-5	1-2
July 27, 1959 (N)	80	226	205	18	25	260	45	-		3-5	1-2
(S)	55	111	205	9	25	235	30	-		3-5	1-2
Aug. 2, 1959 (centre)	100	218	215	15	25	285	17	8	80	>5	3-5
(S)	80	119	200	13	25	305	12	4	67	>5	3-5
Aug. 26, 1959	110	175	240	12	30	310	14	10	71	>5	1-2
July 14, 1960 (N)	60	110	175	18	20	285	14	7	78	>5	3-5
(S)	90	142	215	13	30	285	30			>5	3-5
July 19, 1960	120	213	185	12	35	280	9	15	79	>5	3-5
June 24, 1960	110	149	355	15	25	260	32	1	6	>5	1-2

precisely constant velocity, leaving a hail swath of unchanging width or dropping hail of quite constant size distribution. Our present analysis reveals some of the variations in these parameters in individual storms. Our main attention was focused on twelve fairly severe storms which grossly speaking one would describe as steady.

The twelve storms are listed in Table 3. All of them lasted more than two hours and produced swaths longer than 50 miles. They moved from the west: bearings of the swath starting points ranged from 230° to 310°; speeds ranged from 23 to 42 miles per hour. These speeds, obtained from the reported times at which hail commenced at various points, were reasonably constant along the swath. Maximum hail sizes, as reported by the farmers, in these storms are shown in Fig. 12 (opposite page 10).

Hailstorm spines

Maps showing the geographical location of points at which hail was reported reveal that while the hail tracks often had ragged, ill-defined edges, all had the appearance of having deviated little from straight-line paths. In an attempt to bring out further details of storm paths, separate maps for each storm were plotted for each hail size, the latter being in all cases the maximum hail size noted by the observer. A central curve or spine was then drawn along the length of the swath for every size (see Douglas, Report MW-35). The spines for a particular storm were then superimposed upon one another for comparison. For a steady-state storm, such spines would all be straight lines, parallel to the direction of travel of the storm but would not necessarily be coincident.

Spines for eleven of the storms were close to straight lines, although two of them curved a little near one or both ends. In five cases there was a

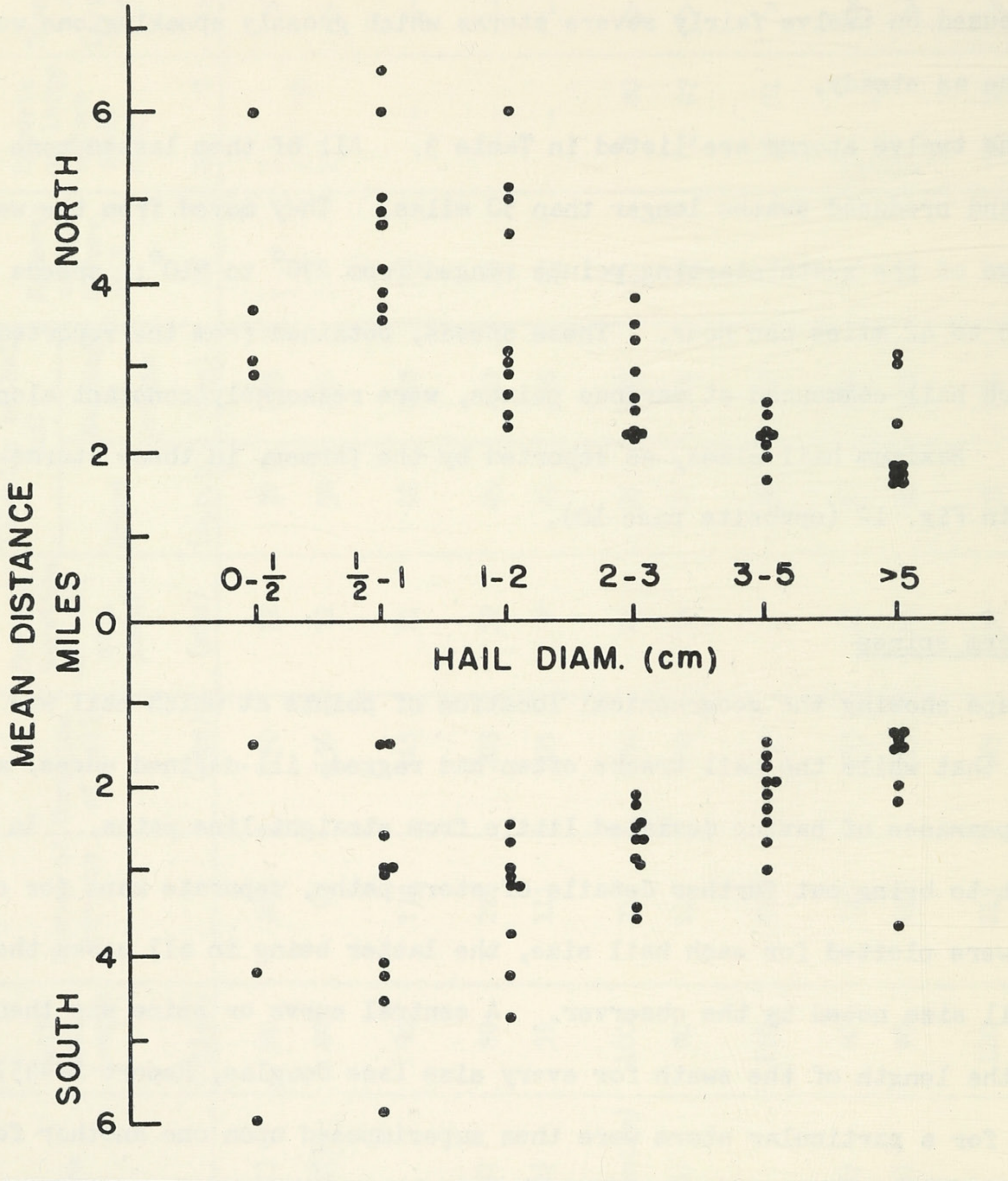

Fig. 4: Bigger hailstones fall closer to the centre of the hail cell.

definite trend of displacement of the spines with maximum hailstone size: in four of them the spines were displaced progressively to the left (of the direction of motion) as hail size decreased; in the fifth case (Aug. 26, 1959), the displacement was in the opposite sense. Mostly, the spines diverged as the storm progressed. The twelfth storm (June 13, 1959) gave spines with significant curvature. This storm has been discussed in detail elsewhere (Douglas, MW-35); for all its considerable length and duration, it was clearly not a steady-state storm.

A feature common to all the storms was that the larger hail was distributed along narrower paths than the smaller hail. This is illustrated by Fig. 4, where the average distances of reported hail locations from the common spine (or where spines differed with maximum hail size, the spine for the largest size) are shown as a function of maximum hailstone size. These distances were taken as the lengths of perpendiculars from the location of a report to the spine. It will be noted that the distances for the smaller hailstones tend to be greater to the left (north) than to the right (south) of the storm, except for Aug. 26, 1959. This agrees with the progressive displacements which were found for the spines. Such a distribution of reports would be produced by a core of bigger hail within, and slightly to the right of centre, of a column of smaller hail.

Hail cell motion and upper winds

In previous reports it was mentioned that hailstorm motion, as revealed by the radar echoes, usually was in reasonable agreement with winds aloft, but that the hail swaths developed somewhat to the right of the directions of motion. These findings are in general agreement with Ludlam's and with observations in the United States. We have called the area on the ground receiving hail at

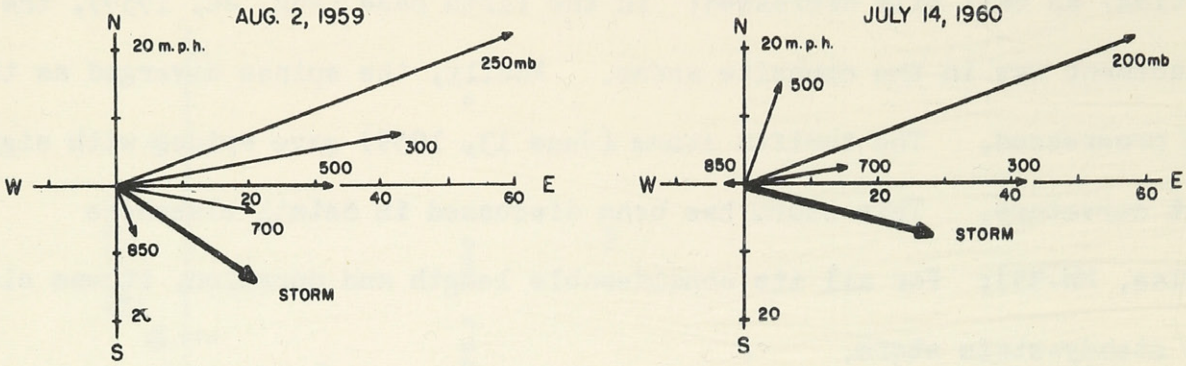

Fig. 5 (left) and Fig. 6: Wind vectors at various levels and storm velocities on August 2, 1959 (south storm) and July 14, 1960 (north and south storms).

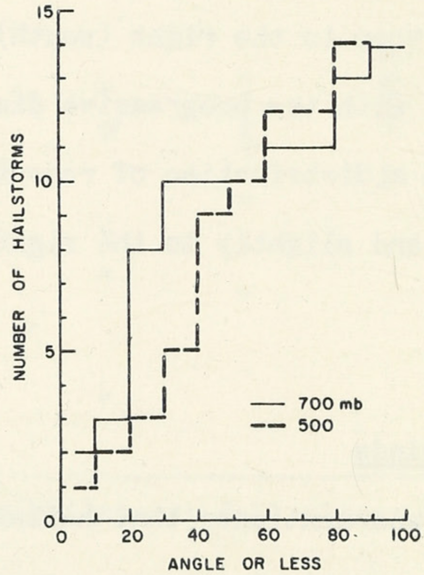

Fig. 7: Cumulative number of hailstorms versus angle, or less, in degrees between hail path and the wind directions at the 700 and 500 mb levels.

any time a hail-cell, and in a straight-forward way determined the cell velocity for the reported hail times and locations. Results are listed in Table 3.

Hail swaths from different storms on the same day were generally parallel to one another, although there are instances of storms which occurred close together in time and space but laid hail swaths differing in directions by up to 25° (see for example the two storms of July 27, 1959, in Table 3, where the bearings of the swaths have been taken as that of the spines for the largest size of hail.) Such differences are possibly the effect of the storms having extended to different heights. Going beyond the storms listed in the Table, a more extreme example occurred on August 2, 1959, when four storms all produced swaths along the lines from WNW to ESE, whereas in the same area other storms which reached much smaller heights (and did not produce hail) moved from the SW, practically at right angles to the swaths.

Radar-echo heights are not available for all storms, so that no detailed study of the correlation of height, wind pattern and cell velocity was attempted. But some general characteristics for all the hailstorms became apparent. The twelve storms all produced swaths along directions to the right of the wind above 700 mb, a level close to 7 kft above ground; cloud base typically being at about 4 or 5 kft. Figs. 5 and 6 show typical examples of winds and hail-cell velocities. There was no obvious correlation between cell speed and wind at any particular height: the heights above ground at which the two speeds agreed ranged from 7 to 28 kft. The cell directions were mostly about 30° to the right of the upper winds, as shown in the cumulative histograms of Fig. 7. A similar plot for the 300 mb level was no different in character from the 700 and 500 mb curves which are shown.

Windshear of about the magnitude shown in Fig. 5 and 6 was present on every hail day. The winds increased from 7 to 20 kft on every day, except on

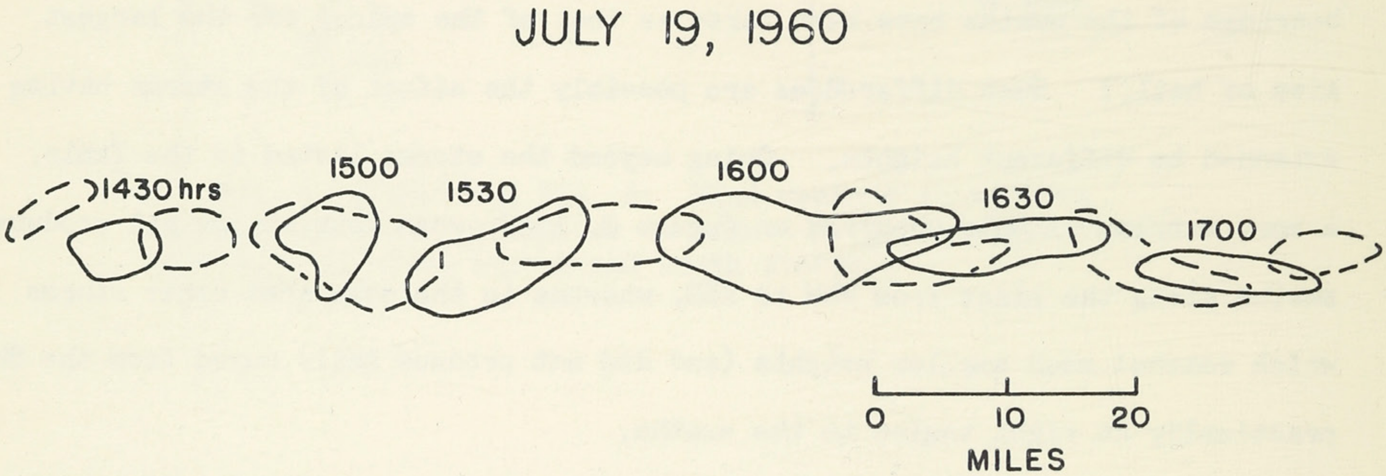

Fig. 8: Hail cells at 15-minute intervals on July 19, 1960. Each envelope, or cell, encloses all points at which it was known to be hailing at a particular time. Times for the solid-line envelopes are shown; the broken lines apply to the intermediate quarter hours.

July 27, 1959 when they decreased from 7 to 15 kft, but then increased up to 20 kft. These observations are based upon wind measurements at 1700 MST at Edmonton which lies to the north of all the storms. Comparison of wind measurements at Edmonton and Calgary (south of all the storms) and comparison of winds 12 hr before and 12 hr after 1700 show that the general conclusions probably would not have been affected had wind measurements been made closer to the storms.

Hail cell size and shape

The area on which hail was falling at an instant - the hail cell - may be found from the reported starting times and durations. Such cells could be delineated with reasonable accuracy for the storms of 1960 and 1961 by using only the reports for which the time of accuracy was stated to be within 5 minutes. As shown by Fig. 1 this included about 60% of the card reports. For the earlier years when no accuracies were given, the average times from points clustered together were used.

The cells for all storms were drawn at 15-minute intervals. Examples are shown in Figs. 8, 9a and 10a. The cells which changed least with time were those of Aug. 2, 1959 (centre storm) and July 19, 1960, which are shown in Figs. 9 and 8, respectively. In the former case, the cells were almost circular while those of the other were elongated with the major axis 3 or 4 times longer than the minor axis, and oriented fairly close to the direction of travel. The other storms had cells which varied considerably in shape and size with time. In some storms (e.g. Fig. 10a at 1600 hrs) two or more separate areas received hail at the same time, while the areas between them had hail shortly before or after. Insofar as it is possible to generalise, the hail cells were mostly variable in shape but were often elongated in the direction of travel.


AUGUST 2, 1959
CARD REPORTS
HAIL INSURANCE
N
1600 hours
1700
1800
DIDSBURY
(a)
1700
1800
0
10
20
MILES
DIDSBURY
(c)
R RAIN FIRST
H HAIL FIRST
• RAIN AND HAIL TOGETHER

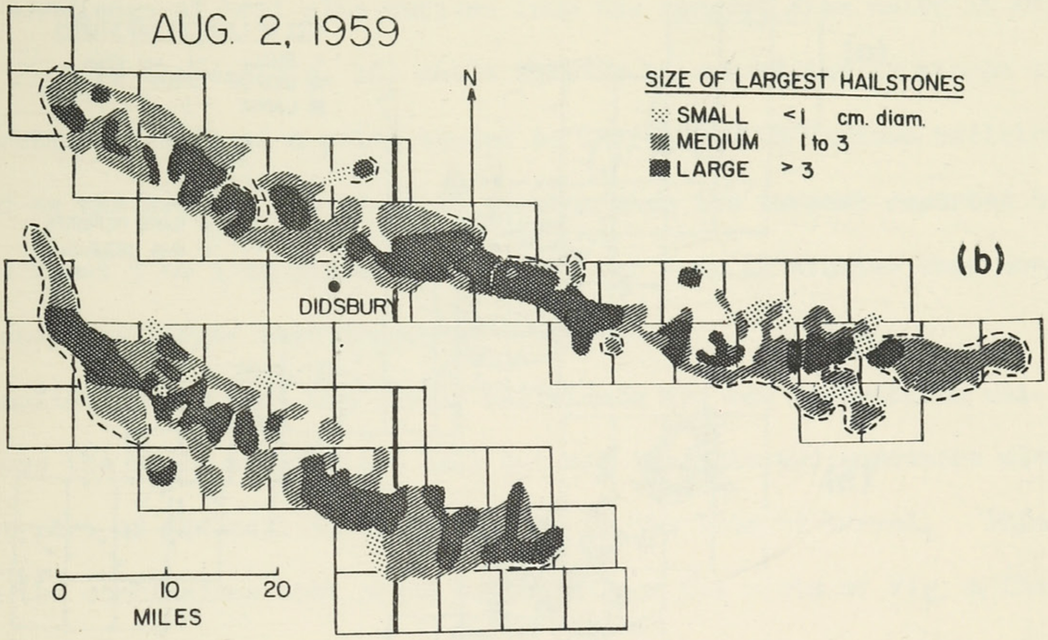

Fig. 9: Storms on August 2, 1959.

(a) (opposite, above) Location of points at which hail was reported.
(b) (above) Probable hail areas have been shaded according to maximum hailstone sizes. Where shaded patches are surrounded by dashed lines, we had not received hail reports from other storms, and thus could not use our technique to full advantage.
(c) (opposite) Rain/hail sequence.

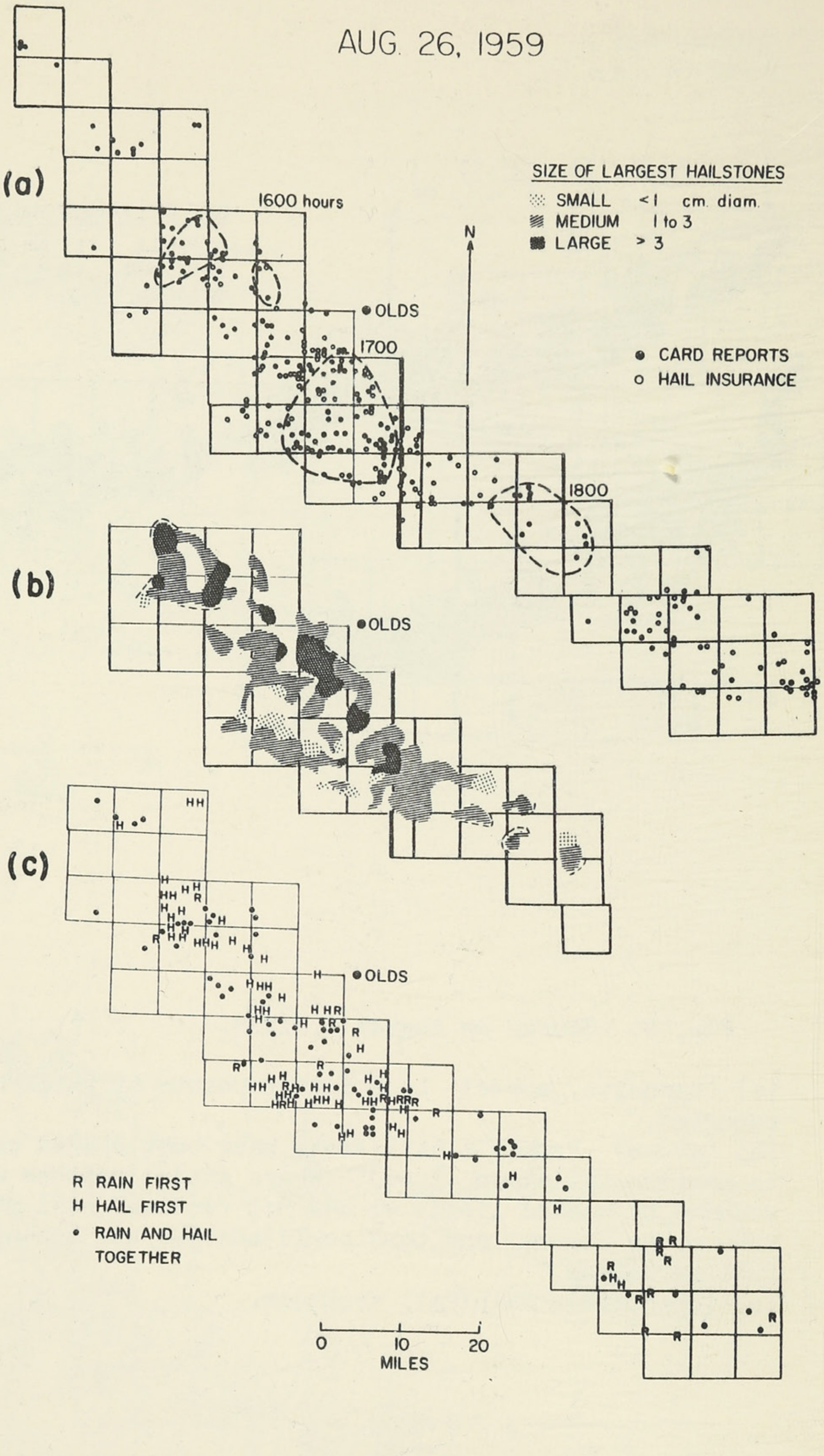

Fig. 10: Storm of August 26, 1959.
(a) Location of points at which hail was reported.
(b) Probable hail areas have been shaded according to maximum hailstone sizes.
(c) Rain/hail sequence.

Information on the distribution of hailstones of different maximum sizes within the cells may be obtained from the reported hail durations and sequence of sizes at given points. (Here and elsewhere it should be remembered that nearly all knowledge of hail size derives from the largest size noted in any report.) Fig. 12 (opposite p. 10) shows that in 10 out of the 12 storms the average duration of hail at a point tended to increase with maximum hailstone size. Hail lasted on the average for 15 to 25 minutes when the largest reported hailstones were about 3 to 5 cm diameter, and only for 5 to 12 minutes when none of the hailstones was larger than 1 cm.

The implication is that the larger hailstones are not distributed uniformly across the whole area of the cell but are concentrated somewhere along the longest part of the cell in the direction of its line of travel. This jibes with the conclusions that could be drawn from the plots of Fig. 4 that the larger hailstones tend to occur along the centre of the storm path.

A few percent of the observers, while not specifically requested to do so, reported on the sequence in which hailstones of various sizes reached the ground: in 9 out of 12 storms (or 8 out of 9, neglecting storms for which there were less than 10 reports of size sequence) 70% or more of the reports stated that the largest hailstones came first. On two days the opposite sequence predominated, viz. June 24, 1960, when 15 out of 16 reports stated that smaller hail preceded larger hail, and July 27, 1959, when all four reports were to this effect. (Sequences are illustrated in Figs. 9c, 10c, and 11c.)

It is interesting to compare these findings with those of Changnon and Stout (1962) who studied three storms in Illinois and found many hail cells to be ellipsoidal with a 2 : 1 ratio of major to minor axis. Typical lengths for these axes were 4 and 2 miles respectively. They found that the smallest hailstones were usually near the leading edge of the cells and the largest ones

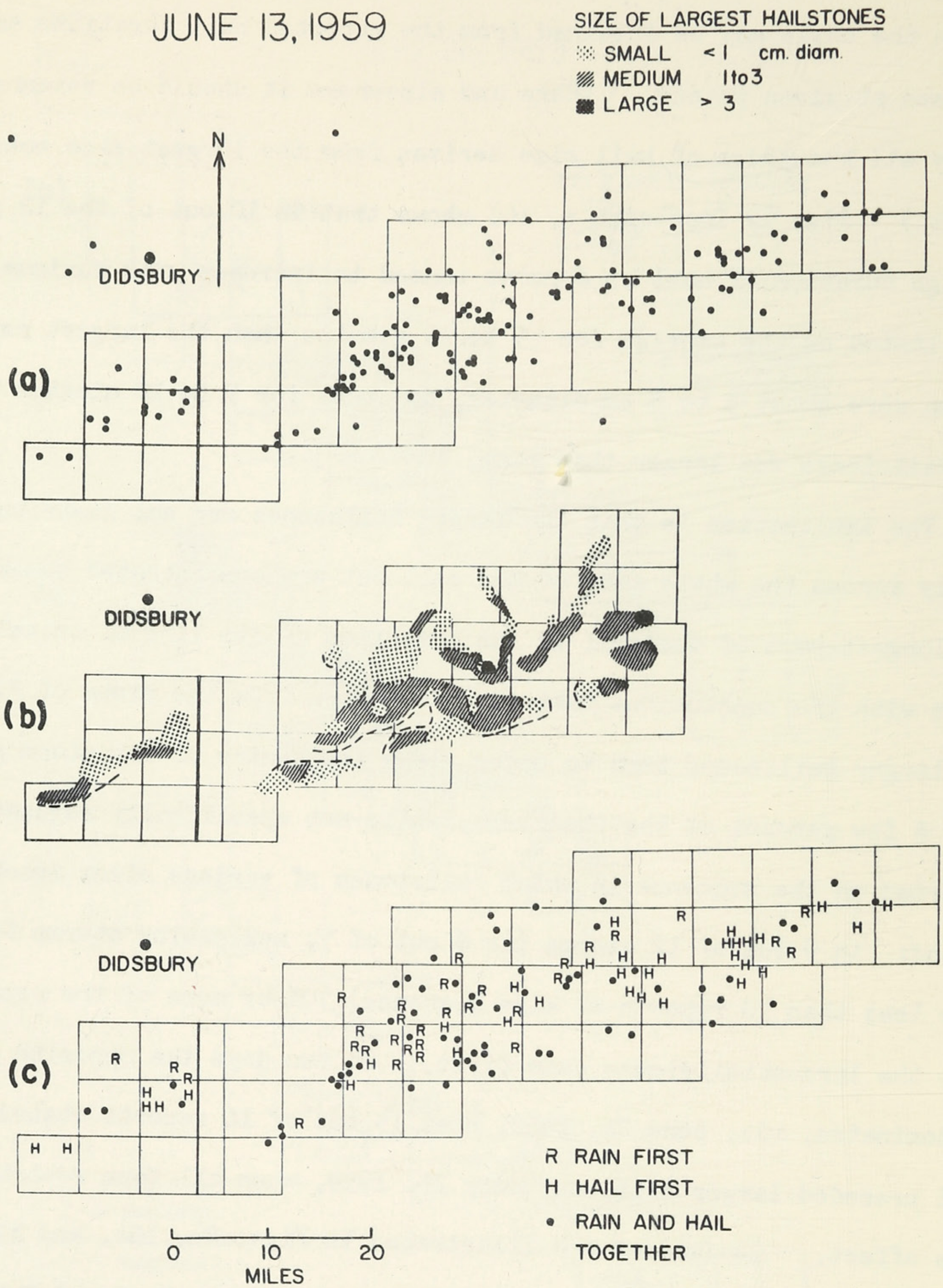

Fig. 11: June 13, 1959.

(a) Location of points at which hail was reported.
(b) Probable hail areas have been shaded according to maximum hailstone sizes.
(c) Rain/hail sequence.

were confined to the trailing edge, mostly the southern part. The cells moved in directions nearly parallel with their major axes and cell velocities and shapes changed rapidly with time. The hail cell was situated to the right of the very much larger rainfall cell.

The principal differences between the Illinois and Alberta cells appear to be that in Alberta cell sizes are much larger (4 to 20 miles across), and the bigger hail tends to be closer to the leading edge. Alberta hail cells, as those in Illinois, were on the right (south) of the main area of precipitation, as indicated by the radar.

Areal hail coverage

The observing network is sufficiently dense to demarcate the boundaries of hail swaths fairly well. Examples as revealed by the reports are shown in Figs. 9a, 10a and 11a. The locations of points from which card reports were received are shown as solid circles, each drawn with a resolution of about half a mile, which generally corresponds to the precision of the information we have. The outstanding problem is a lack of negative reports to verify apparent gaps.

The storms which occurred during the afternoon of Aug. 2, 1959 moved from WNW to ESE (Fig. 9a) at about 25 m.p.h. The centre and southern storms left hail swaths of length 100 and 75 miles, respectively. There were 337 hail reports from these two storms, but even so there are numerous gaps. Information from insurance companies for regions which had suffered crop damage enabled some gaps to be filled, leaving fewer regions of uncertainty. Times and hail sizes are not known for the insurance data, which are shown as circles in Fig. 9a (and also in Fig. 10a). The practice previously followed has been to define a swath roughly as the area within the envelope of minimum perimeter which would enclose all points. Where the radar echo, the area in which hail

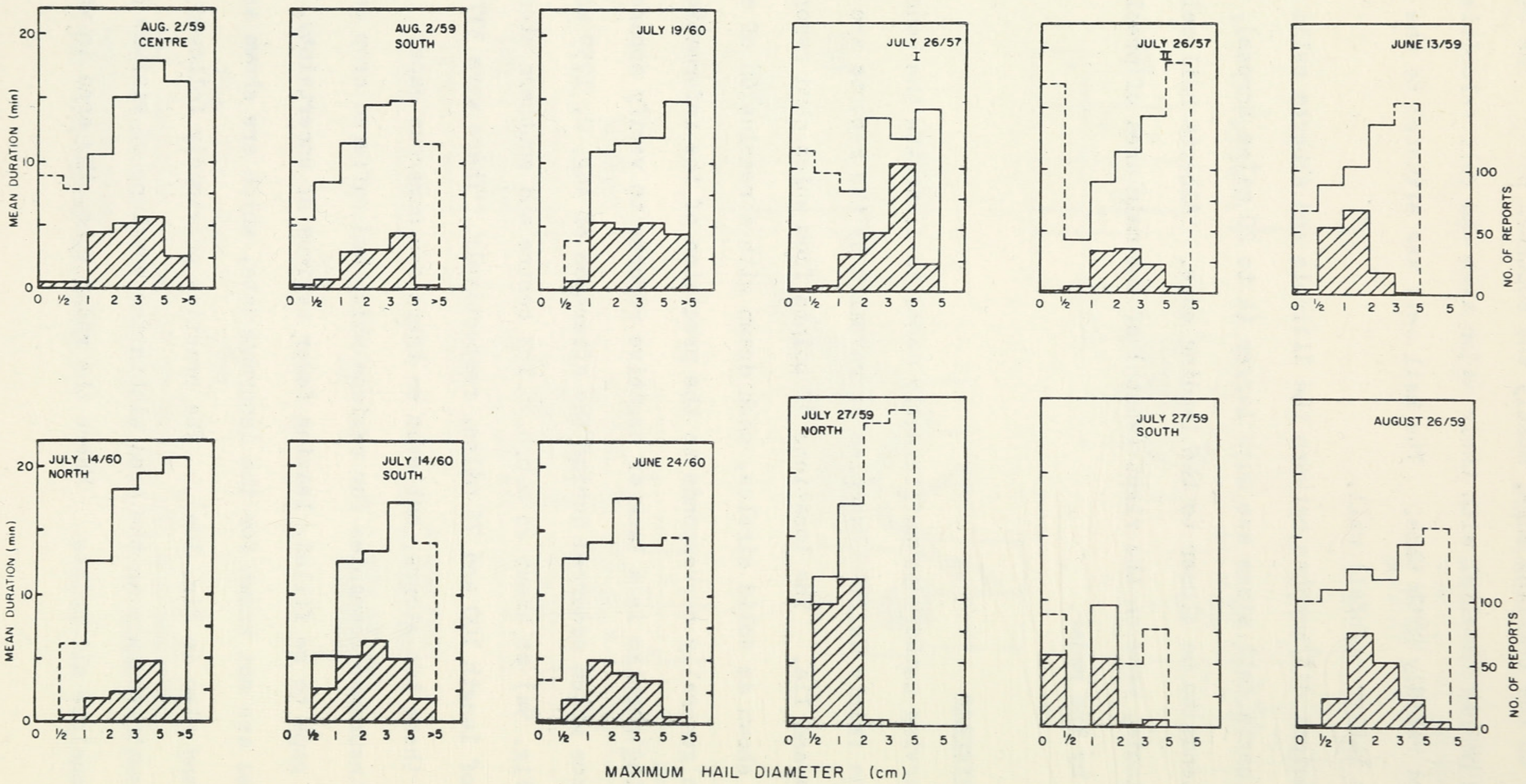

Fig. 12: Average durations of hail versus maximum hailstone size. The hatched histogram shows number of reports against maximum hailstone size. (Information based on less than 10 reports is shown dashed).

was falling at a particular instant (see broken lines in Figs. 9a and 10a) and maximum hail size showed no marked change with time, it was assumed that the hail fallout was also continuous and that gaps were due to incomplete reporting. It will now be shown by a new method that the assumption of swath continuity is often unjustified.

Clearly, there is a strong likelihood that a gap within a particular swath really reflects absence of hail when the area is known to contain observers who reported other hailstorms. Thus, the location of observing points as revealed by reports of hail from other storms may be used, at least as a guide, in determining the hail boundaries of a particular storm. Suppose that randomly distributed over an area $\underline{A}$ there are $\underline{x}$ observers (defined as the number of active hail reporters: i.e. the people who would report all occurrences of hail); the identities and locations of $\underline{b}$ of these are known as a result of their having reported hail on other occasions. If a storm crosses this area and $\underline{a}$ reports of hail are received from it, of which $\underline{c}$ originate from the $\underline{b}$ known observing points, then the probability of hail from this storm falling at any point within area $\underline{A}$ is

$$P = \frac{c}{b} = \frac{a}{x}$$

provided that the $\underline{b}$ observing points are also distributed randomly over the area. Clearly both $\underline{P}$ and $\underline{x}$ can be found from the values of $\underline{a}$, $\underline{b}$ and $\underline{c}$.

Now that the number of active observers $\underline{x}$ within a certain area may be found even though not all of them have had hail, we may determine the variation of density of the observing network from place to place. It was found to vary from 120 observers to 10 or less per 100 square miles, compared with the average for the whole project area of 30 per 100 square miles. It is therefore obvious that any conclusions regarding the areal hail coverage within a swath which

are based solely on the number or spatial density of hail reports can be most misleading. With a knowledge of this spatial density the ambiguity of whether few reports from a certain area mean few observers or small areal hail coverage may be resolved.

The probability P of hail from a particular storm having fallen at any point within a given area is important, in that it also represents the fraction of the given area on which hail fell from this storm. Before describing how details of the hail pattern on the ground are derived from values of the areal hail coverage, possible errors in calculated values of P will be discussed.

The accuracies of calculated values of both P and x will depend (i) on the random distribution of a sufficient number of observers over the area under consideration; and (ii) on the reliability of observers, who in practice may report some occurrences of hail but not others, perhaps because of temporary absences or because of a bias towards reporting the more severe storms. For example, the failure of observers considered reliable to report will make the calculated probabilities too low. Thus, the absence of 20% of the b known observers would make c, and therefore the calculated P, 20% too low.

Some checks of accuracies have been made as follows. The calculated probability was found to be close to unity in several cases. A calculated probability of unity requires two conditions to have been fulfilled: hail from a particular storm fell at all known observing points, and none of these observers failed to report. When there was close to 100% response from the known observers in, say, 50 square miles or more of a swath, it is reasonable to infer that active observers in other parts were not seriously less reliable.

Other checks may be made by selecting different sets of observers from the known ones in a given area and then finding values of P or x for a certain storm. Arbitrary selection - rejection of some observers - will show whether

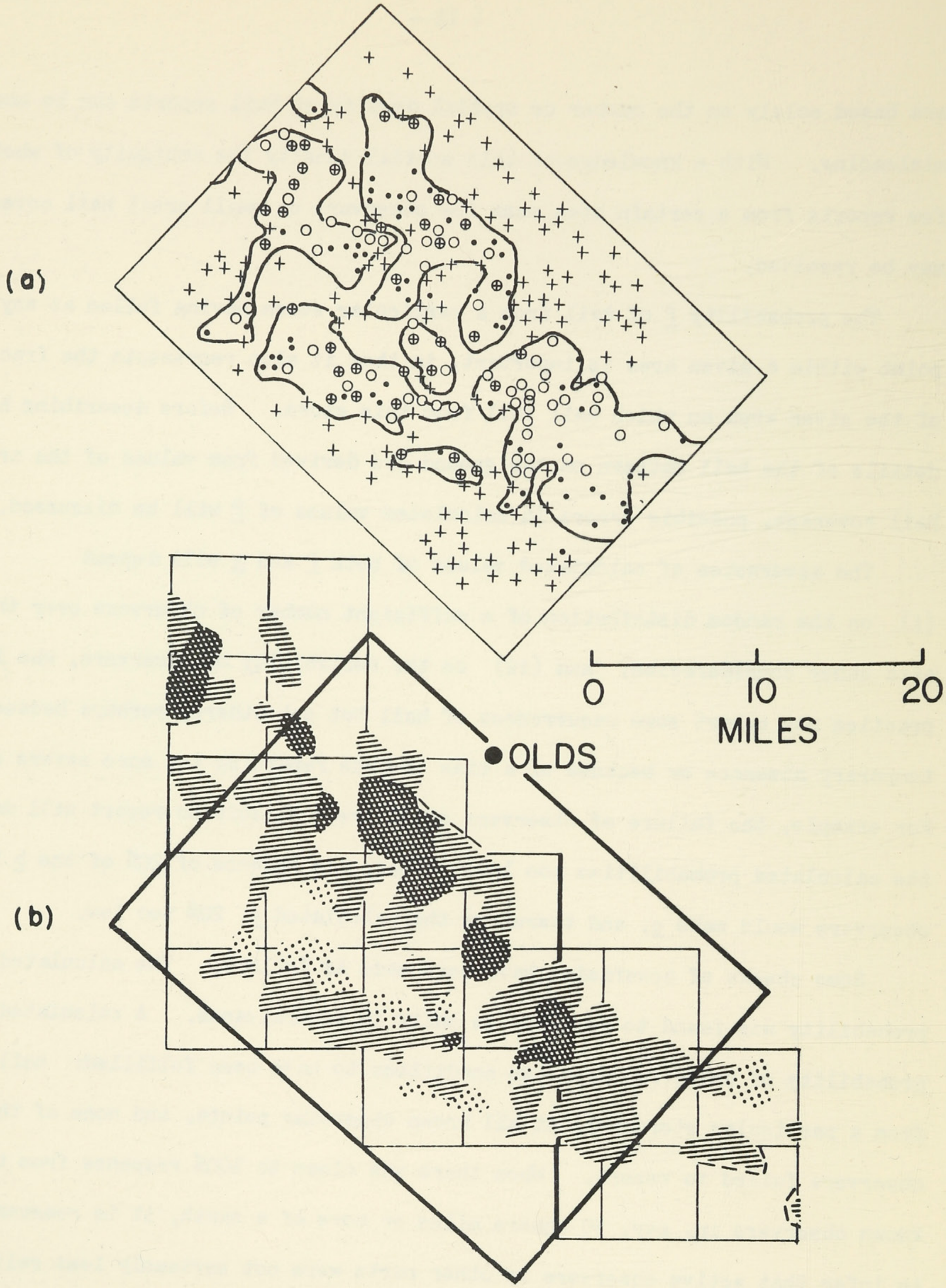

Fig. 13: Part of swath of Aug. 26, 1959. (a) Outline of part of swath, and the raw data on which this outline is based: ○ card reports of hail on Aug. 26, 1959, + card reports of hail on days in 1959 other than Aug. 26, 1959, ⊕ card reports of hail on Aug. 26, 1959 and at least one other day, ● insurance reports of hail on Aug. 26, 1959. (b) Part of the swath in its final form, with shading suggesting maximum hail size, as in Fig. 10. (Oblique rectangles cover same area.)

there are sufficient observing points. Sets made up of data from the same year will reveal whether the observing network changed significantly from year to year. Indications were that the network remained effectively the same from year to year, but it was possible to verify this only for such small areas that the practice has been to compute probabilities only from data obtained in the same year.

In numerous instances, computed values of P for areas greater than 50 square miles within hail swaths are 0.5 or less, and errors are estimated to be less than 0.25. This implies that a great deal of the areas received no hail.

A number of hail swaths have been examined in the light of the above ideas, and calculated probabilities (fractional areal hail coverages) were used to determine the areas most likely to have had hail. Some results are illustrated in Figs. 9b, 10b and 11b, where the hail areas in the swaths are shown shaded. Fig. 13 is an excerpt from Fig. 10a and b, shown to a larger scale. Our procedure for drawing the shaded areas will now be explained. Each such area includes all points at which hail was known to have fallen from the particular storm; it excludes points which had hail from other storms only; and it extends to cover the calculated fraction of the total area. The type of shading indicates maximum hail sizes observed. Insurance reports were not used in finding probabilities but only as a guide when shading the hail areas. Where a hail swath passes through an area from which no reports from other storms were available to us, our procedure clearly breaks down; in such cases the edges of the shaded areas were drawn quite roughly, and were surrounded by a dashed line. The example illustrated in Fig. 13 is taken from an area of rather high density of active observers: about 60 per 100 square miles. When about half the data are rejected arbitrarily very nearly the same results as in Fig. 13b are obtained, suggesting that the data are representative.

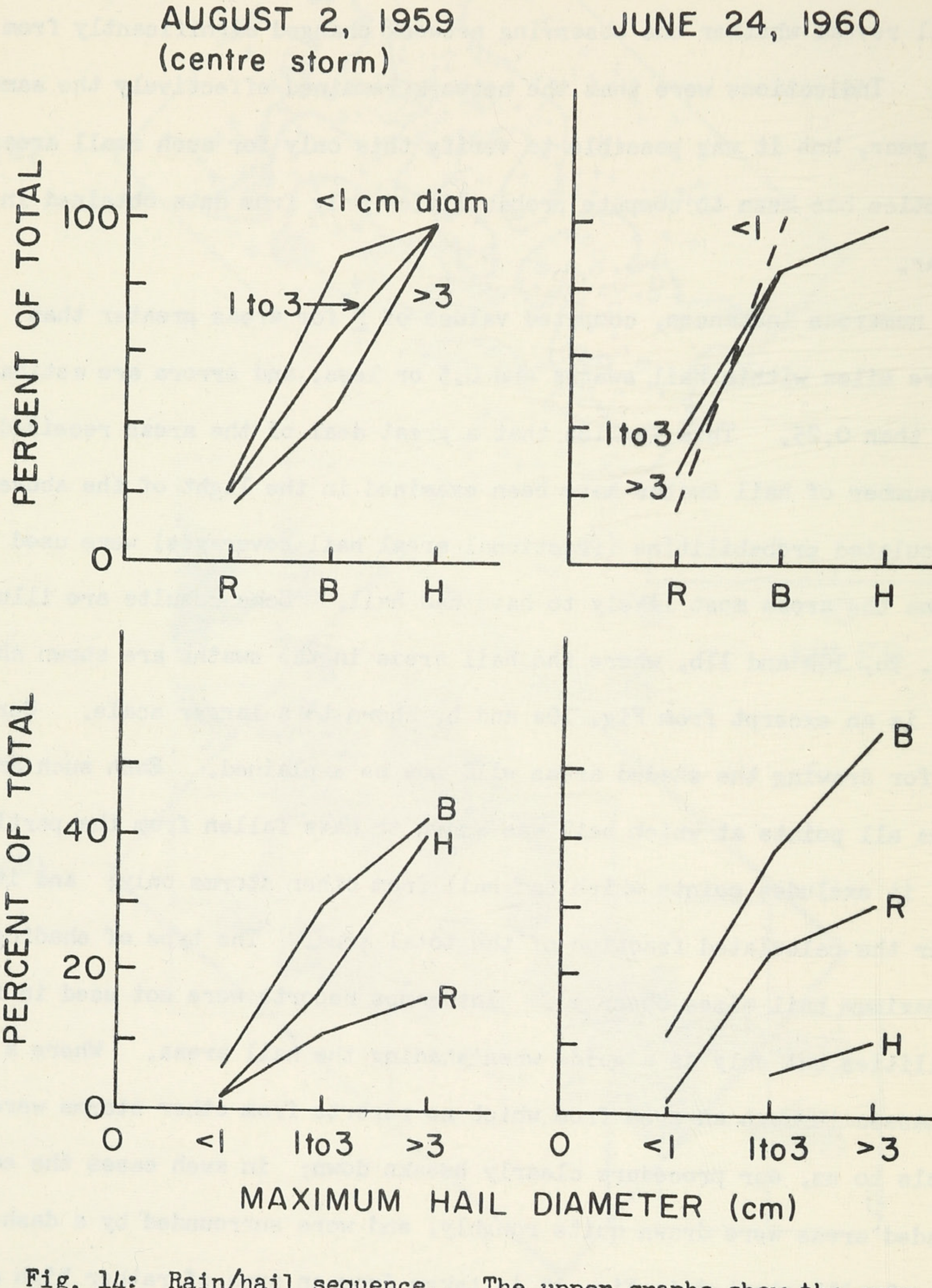

Fig. 14: Rain/hail sequence. The upper graphs show the cumulative percentage number of reports for each of three size groups: viz. small (largest hail was<1 cm diam), medium (1 to 3 cm) and large (>3 cm) versus the sequences, R (rain before hail), B (both rain and hail started together) and H (hail before rain). On the lower graphs the ordinate is cumulative percentage of the total number of reports and other symbols are as above.

The examples in Figs. 9 to 11 show that patchiness of the hail pattern is a characteristic of all of them. This patchiness suggests that the process of hail generation may be intermittent, even when it continues for several hours. Other evidences of the discontinuity of the storm were provided by changes of the radar echo, and changes of the size of the largest hail at different places along the swath. Also, there were occasional reports from most of the storms stating that the hail had come in several bursts. In other storms, the discontinuity was not apparent until revealed by the technique just described. But even here, additional information may support our current impression. For example, observers were asked to state on the hail-reporting cards the sequence in which rain and hail commenced. The majority of such reports state that hail preceded rain or that rain and hail began simultaneously, while relatively few reported rain which preceded hail. These different categories of reports tend to originate from places clustered together, and so indicate changes in character of the storm as it moved along.

Rain/Hail Sequence

The percentage of reports in the two categories: "rain before hail" and "large hail before small hail" are listed in Table 3 (opposite p. 4). Only in a minority of cases, is rain seen to precede hail; in all storms except two, about half the reports mentioned that hail and rain began to fall at the same time; the exceptions are the two storms of July 26, 1957, for which in 87% of the reports the hail was said to have arrived first. We have attempted to relate the rain/hail sequence, to the maximum size of the hail. This is illustrated for two storms in Fig. 14, where the categories used are: "hail before rain" (H), "rain before hail" (R), and "hail and rain starting together" (B). The data shown for one storm of Aug. 2, 1959 are typical for situations where

Editor's Note: Studies of the sort recommended opposite by Dr. Carte were carried out by G. N. Williams during the 1962 field programme in Alberta. Williams' surveys did not cover really extensive swaths of the size and severity studied by Carte; but among the seven smaller storms about which we now have good information (positive and negative reports) a good measure of continuity is found in at least three cases.

the hail usually came before the rain; the June 24, 1960 case is representative for storms showing the opposite tendency. In the former case, it may be noted that the "hail before rain" (H) tendency is relatively more pronounced the larger the maximum hail size. The data suggest an extension of this: for storms with a pronounced H-tendency, big hail tends to precede small hail; while vice versa, when the rain came first, small hail followed, followed in turn by large hail. (Cf. the item June 24, 1960, in Table 3).

It is noteworthy that the tendency toward hail first or rain first changes as the storm progresses. H and R observations are therefore often clustered together - as can be seen in Figs. 9c, 10c and 11c. The suggestion is made that the observed complex precipitation patterns could just possibly have been produced by the simultaneous existence of two or more precipitation generating cells within the clouds, continually waxing and waning in relative intensities.

3. SUMMARY

(i) Radar echoes often extended to the left (north) of the swath but never significantly beyond the right hand (southern) boundary of the hail swath.

(ii) Hail swaths were oriented to the right of the upper winds.

(iii) Larger hail was dispersed less on either side of the spines than smaller hail. Also, the average duration at a point was longest at places which had the biggest hail.

(iv) The most commonly observed sequence at a point was large hail, followed by smaller hail and rain. The reverse sequence prevailed in some storms even though the wind pattern was basically the same for all days studied.

To harden some of our conclusions, every effort should continue to be made to obtain further information on the continuity or otherwise of hail swaths. In Alberta, it is planned to conduct detailed field surveys in order to supplement the card data and, particularly, to seek negative reports from areas in the vicinity of hail which are suspected of having been spared.