COLORADO HAILSTORM STUDIES

1960-61

A Progress Report

on

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Prepared by the Hail Research Staff for 1961

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INTRODUCTION

Colorado State University became involved in studies of hail for the first time in the summer of 1959. At this time representatives of local farm groups in northeastern Colorado approached Colorado State University for an evaluation of a weather modification program conducted there for the purpose of reducing hail damage.

In 1960 a more basic study of the characteristics of formation of hail was begun. The successive objectives of these studies begun in 1960 consisted of the following:

1. Development of instrumentation for measuring of physical characteristics, duration and frequency of hail at the ground.
2. Organization of a field network for systematic observation of hail and precipitation events with the instrumentation developed.
3. Three-dimensional field measurements and analyses of peripheral data to provide a thorough description of hail events.
4. Weather modification experiments based on the knowledge gained on the preceding steps, with the objective of attempting to reduce damaging hail occurrence as much as possible.

The initial grant (NSF G-1234) gave support for the development of the first two of these four phases. The second grant (NSF G-17964) gave partial support for development of the environmental studies.

The purpose of this report is to summarize the work done to date and to make it a matter of record for future reference in continuing the studies of hail.

II. WORK ACCOMPLISHED

A. Instrumentation (by C. Thomas)

1. Indicator

a. Description

The indicator consists of a stand, a 6" x 6" x 1/2" styrofoam base, he light[1] and heavy [2] gage aluminum foil and the cover. The 2" x 6" heavy foil strip, used in 1959 and 1960, was replaced in 1961 by a 4" x 4" sheet of heavy foil and placed in the center of the 6" x 6" pocket between the light gage aluminum and styrofoam.

In case of large hail stones, it is very likely that the 2-inch width would not be enough to catch the whole dents, whereas, with a 4" x 4" sheet of foil, the chances of having the whole dent would be greater.

On the stand is placed the styrofoam, the 4-inch square heavy foil, the 10-inch square light foil, and the cover in that order, and the stand is nailed to a fence post. The cover, having a 5" x 5" opening on top, protects the styrofoam pockets and holds them in place.[3]

b. Purpose

The indicator was designed to provide a way of measuring the energy from falling hail stones at some particular part of

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[1] "Light foil" refers to "Reynolds Wrap, Heavy Duty" household aluminum foil.

[2] "Heavy foil" refers to OO - A - 561B, 280 aluminum foil sheet, mill finish, 34 gage.

[3] "Hailstorm Damage to Crops in Northeastern Colorado and an Analysis of Precipitation Anomalies Associated with a Cloud-Seeding Program in 1959" by Richard A. Schleusener, Figure 3, page 415.

the network for each storm individually. The intensity of a hail storm may be interpreted from the indicator in terms of ft-lbs of impact energy per square foot.

c. What data were obtained

(1) Network data

The indicators were checked periodically in order to pick up the hail-damaged indicators as soon after the hail storm as possible to limit the hail damage per indicator to one hail storm. Indicators with hail dents from more than one storm are difficult to interpret, because they show only the summed effect of the two storms together and not each storm individually. A "Hail Indicator Data Sheet" is used, as shown in Table 1, to keep a record of the visits made to each indicator and the other important data as shown on Table 1.

The 1960 data are not shown on the sample "Hail Indicator Data Sheet" because indicator number 1003, used as a sample in Table 1, was added to the network in 1961.

When the indicator was damaged by hail, the date of the hail was determined from people living nearby. The date of the hail and the pick-up date and indicator number were recorded on the hail-damaged packet itself. After the hail-damaged packets were brought in from the network, the packet was dismantled, the light foil is thrown away, the styrofoam is retained for further use whenever possible, and the heavy foil only is kept for future reference. The

hail date, pick-up date, and indicator number is then transferred from the light foil to the heavy foil during the dismantling, so that the heavy foil is all that was retained from indicators that were damaged by hail.

(2) Energy data

a. Total energy (E_{total})

The energy numbers are determined with the aid of the "Hail Indicator Computation Sheet," as shown in Table II.

The size distribution of all the dents on the 16 in^2 of heavy foil was determined according to the size class and the actual length and width of each dent within the size class. This was accomplished by using pen and ink to mark the dents as measurements are made of each dent. Measuring the dents was difficult because it was important that each dent be measured with the same method in order to get consistent and acceptable results.*

The dents were measured with a calibrated scale determined experimentally by dropping marbles and ball-bearings of different diameters and observing the size of the dent made by each on the hail indicators. Hence, the calibration of the scale (plastic triangle) is such

*The inaccuracies in the energy values is explained in "An Energy Method for Relative Estimates of Hail Intensity," by Richard A. Schleusener and Paul C. Jennings. Bull. of the Am. Meteor. Soc., Vol. No. 7, July 1960, pp. 372-376.

Sample
HAIL INDICATOR
COMPUTATION SHEET

MAXIMUM SIZE ENERGY 400

INDICATOR NUMBER 140

DATE OF PICK-UP 16 June 61

DATE OF HAIL 28 May, 19 61

DATE OF COMPUTATION 12 July 61 BY GDT

Size 1 $\frac{1}{8}$ ($0 - \frac{3}{16}$)	Size 2 $\frac{1}{4}$ ($\frac{3}{16} - \frac{3}{8}$)	Size 3 $\frac{1}{2}$ ($\frac{3}{8} - \frac{5}{8}$)	Size 4 $\frac{3}{4}$ ($\frac{5}{8} - \frac{7}{8}$)	Size 5 ($\frac{7}{8} - 1\frac{1}{2}$)	~~Size 6 Greater than $1\frac{1}{2}$~~	
No. L & W 60 - 1x1	No. L & W 16 - 3x3 40 - 2x2	No. L & W 4 - 5x4 8 - 4x4	No. L & W 4 - 7x4	No. L & W	~~No. L & W~~ MSE (Maximum Size Energy)	
Ave.:	Ave.:	Ave.:	Ave.:	Ave.:	~~Ave.~~:	
Total No. 60 On Area of 16 Dents/in^2 3.75 Ave. Area .01 Energy No. 5.6	Total No. 56 On Area of 16 Dents/in^2 3.5 Ave. Area ~~.06~~ .054 Energy No. ~~290~~ 250	Total No. 12 On Area of 16 Dents/in^2 .75 Ave. Area .173 Energy No. 20.0	Total No. 4 On Area of 16 Dents/in^2 .25 Ave. Area .28 Energy No. 12.0	Total No. On Area of Dents/in^2 Ave. Area Energy No.	Total No. 132 On Area of 16 Dents/in^2 8.25 ~~Ave.~~ Area .28 Energy No. 400	Largest Stone Length 7 Width 4 L/W 1.75 ΣE ~~666~~ 626

TABLE II

that the dimensions marked on the triangle correspond to the "dent diameter" for each of the size classes. The relation between stone diameter anddent diameter as determined experimentally was plotted to form the curve shown in Figure 1 to aid in calibrating the scale.

The total number of dents within each size class on the 16 in.^{2} of area gives the dents/in.^{2} for each size class. The average dent area was determined by a "weighted average" which depends on the number of dents with different lengths and widths itself. By entering the "dent area" and "dents/in.^{2}" versus the "energy in ft.-lb/ft^2" on an appropriate graph[5], the total impact energy be found for each size class. Then the energy numbers for each size class are added to give the total impact energy observed by the indicator.

These procedures are illustrated by the following example in reference to Table 2:

> Analysis of 16 square inches of heavy foil shows 60 dents of size one. Referring to Table 2, we find 60 dents, all with a length of 0.1 inch and a width of 0.1 inch. Since the total number of dents in size one is 60 on an area of 16 in.^{2}, we may divide 60 by 16 and obtain 3.75 dents/in.^{2}. Entering the graph with 3.75 dents per square inch and dent "area" of 0.01 gives an energy number of 5.6 ft-lb/ft^2.

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[5]Bid, Figure 6, page 375.

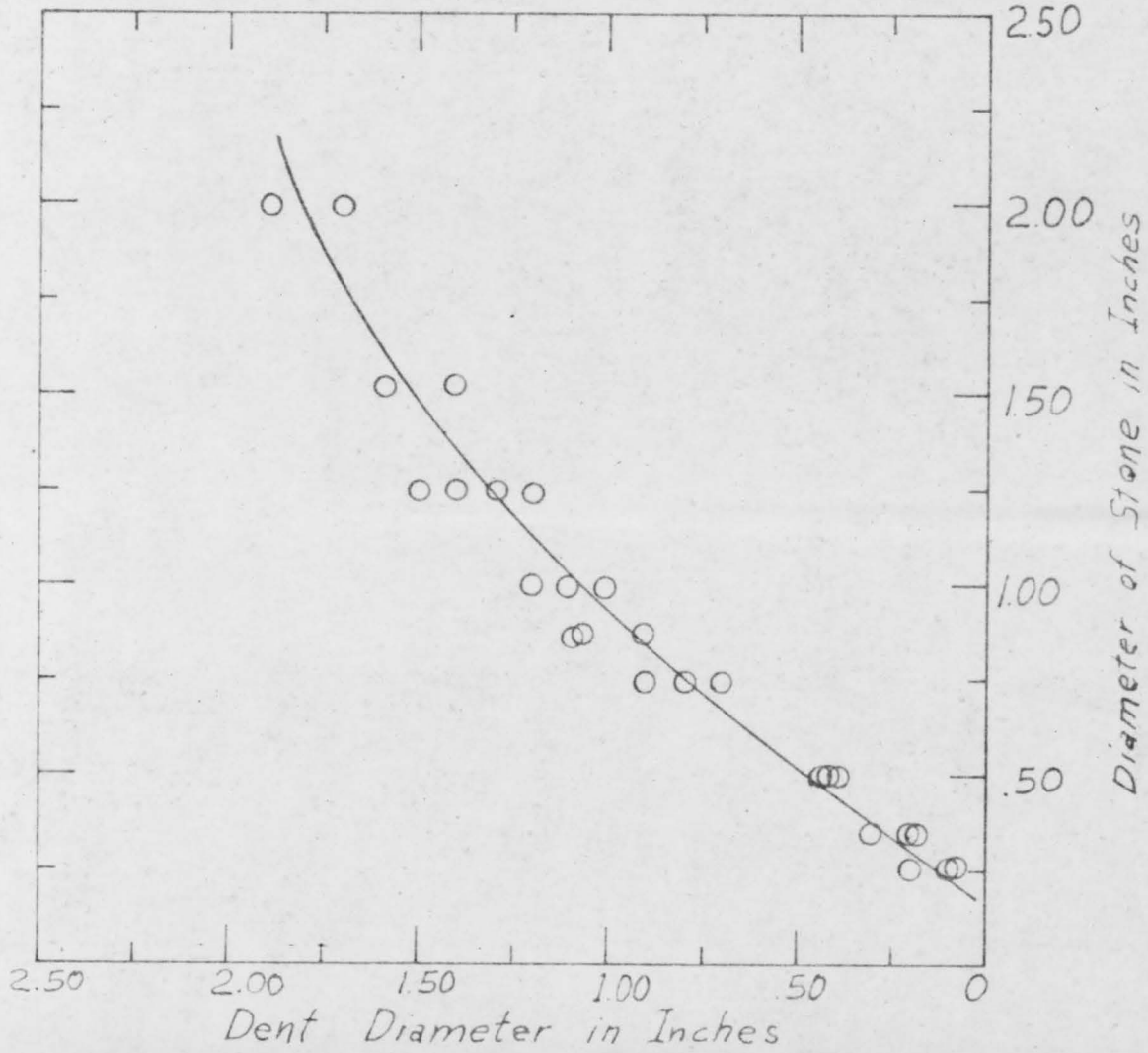

Fig 1 Relation of stone diameter to dent diameter (Heavy fall)

In the foregoing example it is easy to see that the average area is 0.01 in.^{2}, but suppose the dents are measured as follows:

16 - 0.3 in. by 0.3 in. (size 2)

40 - 0.2 in. by 0.2 in.

Then the total number of dents would be 56 on an area of 16 in.^{2} or 3.5 dents/in.^{2}, and the average area would be computed as follows:

$$16 \times .09 = 1.44$$

$$\underline{40} \times .04 = \underline{1.60}$$

$$56 \qquad 3.04$$

$$\text{weighted ave.} = \frac{3.04}{56} = 0.054 \text{ in.}^2.$$

b. Maximum energy (E_{max})

Another energy number, called E_{max}, is computed on the assumption that all the dents are of the largest size. In Table 2, for example, the total number of all the different sizes of dents is 132 on the 16 in.^{2} of heavy foil. There are 8.25 dents/in.^{2}. The largest dent was 0.7 in. x 0.4 in. so that the dent area used would be 0.28 in.^{2} and when entered on the "Energy Graph" with the 8.25 dents/in.^{2}, the "Maximum Size Energy" (MSE) is found to be 400 ft-lbs/ft.^{2}.

c. Network maps of hail impact energies

The total energy values were used in the data reduction system to show the relative hailstorm intensity at various points throughout the storm

movement. This was accomplished by plotting the energy values of all damaged indicators for each day on the network map of Northeastern Colorado at the indicator sites. This network map of hail impact energies, together with the radar data and stereo-cloud photos was used to describe cloud formations of hail storms.

d. Cumulative frequency (percent) of hail impact energy

The total energy (E_{total}) values for 1960 and 1961 were used to plot a graph of the accumulated relative frequency (percent) of energy numbers versus the energy values. The maximum energy values were also used for 1959 (seeded), 1959 (unseeded), 1960, and 1961 to plot a similar graph. This graph showed that the seeded days of 1959 produced hail with less impact energy than the unseeded days of 1959, 1960 and 1961.[6]

e. Volume of hail fall

Table 3 shows the "total dents per square inch" for each time period by size class summed up over all the network indicators damaged during each time period. In 1960, the network consisted of indicators 1-99. In 1961, indicators numbered 1001-1016 was added to bring the total number of network indicators to 115.

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[6]These graphs are shown in Figure 7 of "Characteristics of Hailstorms in the Colorado State University Network, 1960-1961" by Richard A. Schleusener and Lewis O. Grant and presented at the Ninth Weather Radar Conference, 1961.

TABLE III

TOTAL DENTS PER SQUARE INCH

1960
(99 indicators)

SIZE	1	2	3	4	5
15-31 May	224.53	25.58	3.09	0.33	0.34
June	177.46	39.58	3.32	0.45	0.08
July	28.06	1.72	0.00	0.00	0.00
1-15 Aug.	12.00	2.44	0.22	0.00	0.00
* Season	442.05	69.32	6.63	0.78	0.42
15-31 Aug.	7.15	1.37	0.32	0.00	0.00
Sept.	40.27	5.60	0.10	0.00	0.00
No Date	2.90	1.20	0.00	0.00	0.00

1961
(115 indicators)

SIZE	1	2	3	4	5
1-15 May	197.16	64.88	5.48	0.12	0.00
15-31 May	58.44	19.08	1.74	0.50	0.00
June	184.66	75.65	22.22	5.67	0.25
July	83.47	74.98	13.69	1.37	0.06
1-15 Aug.	3.62	1.88	0.00	0.00	0.00
* Season	330.19	171.59	37.65	7.54	0.31

* The "Season" includes 15 May Through 15 August.

The network of indicators does not include the indicators serviced by cooperative observers.

Totals for the season were used to show the relative magnitudes of hailfall for the 1960 season and the 1961 season. Additional periods are listed in Table 3 in order to include all damaged indicators even though they were damaged by hail which occurred either before or after the regular season (15 May - 15 August.).

Table 4 was prepared using the season totals of of dents/in.^{2} (Table 3) which were divided by the number of indicators used in the network during the season to obtain a value of dents/in.^{2}/indicator. This value was multiplied by the volume of the hail stone in each size class to obtain the magnitude of hailfall in cubic inches of ice per square inch of indicator for each size of hailstones which fell during the regular season.

The total amount of ice which fell during the full season including all sizes was found to be 0.0196 in.^{2}/in.^{2} for the 1960 season and 0.053 for the 1961 season. The 1961 value is approximately 2.7 times greater than the 1960 value and this indicates that in 1961 the relative magnitude of hailfall was greater than in 1960, even though the data show that more stones in the larger size classes were produced in 1960.

Distribution of volumes of ice per unit area by stone size classes, 1960-61

TABLE 4.

Stone Size #-Dia.-Vol. (in.)-(in.³)	† 1960 Season Σ Dent/in.²	N = Σ/99 Dents/in.²/ind.	N·vol. in.³/in.²	%	† 1961 Season Σ Dents/in.²	N = Σ/115 Dents/in.²/ind.	N·vol. in.³/in.²	%
1-(1/8):.00102	442.05	4.465	.004554	23	330.19	2.8712	.002929	6
2-(1/4):.0082	69.32	.700	.005740	30	171.59	1.4920	.012234	23
3-(1/2):.0655	6.63	.067	.004381	22	37.65	.3274	.021445	40
4-(3/4):.2210	0.78	.0079	.001741	9	7.54	.0656	.014498	27
5-(1 1/8):.7480	0.42	.0042	.003171	16	0.31	.0027	.002020	4
			.019587	100			.053126	100

COMPUTATIONS

$$3000\ \frac{mi.^2}{NE\ Colo.} = 3000\ \frac{mi.^2}{NE\ Colo.} \times 640\ \frac{ac.}{mi.^2} \times 43560\ \frac{ft.^2}{ac.} \times 144\ \frac{in.^2}{ft.^2} = 12.04347 \times 10^{12}\ \frac{in.^2}{NE\ Colo.}$$

1960

$$19.587 \times 10^{-3}\ \frac{in.^3\ ice}{in.^2} = 19.587 \times 10^{-3}\ \frac{in.^3\ ice}{in.^2} \times \frac{1\ ft.^3}{1728\ in.^3} \times \frac{56\ Lb.\ ice}{ft.^3} \times \frac{1\ Ton}{2000\ Lb.} \times$$

$$\times 12.04347 \times 10^{12}\ \frac{in.^2}{NE\ Colo.} = 3{,}822{,}230\ \frac{Tons\ of\ ice}{NE\ Colo.}$$

1961

In similar manner:

$$5.3126 \times 10^{-2}\ \frac{in.^3\ ice}{in.^2} = 10{,}367{,}018\ \frac{Tons\ of\ ice}{NE\ Colo.}$$

† See Table III.

In 1960, 16 percent of the total volume of hail occurred in the 1-1/8 or larger size class while in 1961 only 4 percent occurred in this size class.[7] It appears that most of the hail impact energy comes from the smaller stones in both years.

f. Hail impact energy by size class

Using the total dents/in.^{2}/indicator in each size class from Table 4, the hail impact energy by size class was computed and tabulated as shown in Table 5. From the stone size in each size class, the associated dent size was found from the curve in Figure 1, and then the dent area was found for each size class. Then by entering the "dent area" and "dents/in.^{2}", on the logarithmic graph[8], the energy number was found for each stone size for the 1960 and 1961 hail seasons.

According to Figure 1, the 1/8 in. stone would not make a dent at all and therefore the impact energy for size 1 was recorded as zero in Table 5, even though there undoubtedly was some energy associated with size 1.

Table 5 shows that in 1960, 32 percent of the hail impact energy came from the stones in size 5 (1-1/8 inches and larger) in 1961, only 6 percent of the hail impact energy came from stones of this size. This

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[7] Ibid, Table 4

[8] Op. cit. Figure 6, page 375

1960 SEASON*

Size #	Stone Size (in)	Dent Size (in.)	Dent Area (in.²)	$N = \frac{\Sigma}{99}$ (dents/in.²)	Energy/Stone (Ft.-Lb./Ft.²)	%
1	1/8 (.125)	0.0	0.0	4.465	0.0	0.0
2	1/4 (.250)	.130	.017	.700	1.6	22
3	1/2 (.500)	.470	.221	.067	2.4	32
4	3/4 (.750)	.780	.608	.008	1.0	14
5	1 1/8 (1.125)	1.200	1.440	.004	2.4	32
					7.4	100%

1961 SEASON*

Size #	Dent Area (in.²)	$N = \frac{\Sigma}{115}$ (dents/in.²)	Energy/Stone (Ft.-Lb./Ft.²)	%
1	0.0	2.871	0.0	0.0
2	.017	1.492	3.4	13
3	.221	.327	12.0	47
4	.608	.066	8.6	34
5	1.440	.003	1.5	6
			25.5	100%

Table 5. Distribution of impact energies by size class of stones, 1960-61.

* 15 May - 15 August

confirms the fact that in 1961, the greater part of the hail impact energy came from the smaller sizes, more than in 1960. In 1961 there were fewer large stones, but the large number of small stones produced so much energy that 1961 had more impact energy on the average than 1960. The 1/2 in. stones (size 3) produced a large amount of energy in both years. In 1961 47 percent of the hail impact energy came from this size class.

It is of interest to compare the data from Tables 4 and 5 with records of sugar beet damage in Northeastern Colorado. The following on beat damage is from Mr. Lyman Andrews, Southern District Manager of Great Western Sugar Company, and refers to damage to beets in their Southern District, which includes all of northern and eastern Colorado, some acreage in Nebraska east of Julesburg, and in the vicinity of Holdrege, Nebraska.

		Volume of ice, in.^{3}/in.^{2} (Table 4)	Impact Energy ft-lb/ft^2 (Table 5)	Total acres of beets damaged (Mr. Andrews)
	1960	.020	7.4	41,428
	1961	.053	25.5	124,634
Ratio	$\frac{1961}{1960}$	2.65:1	3.45:1	3.0:1

2. Mouse Traps

a. Purpose

The Mouse Traps are timing devices developed to give the time of first hail fall during a storm at different locations throughout the network area.

b. Physical construction

The hail timing device as shown in Figure 2 has an aluminum lever with a paddle on one end and a spring and release wire on the other end. The lever is suspended on a fulcrum near its midpoint. The aluminum lever and its associated parts are shown in a sketch in Figure 3. A regular mouse trap is used together with wire, paper clips, nails, and string to form the triggering mechanism as shown in Figure 4. The clock, mousetrap, lever, and all the associated parts are shielded from the weather by a case (made of 1 inch pine).

There were many changes made on the timing device throughout the season to make it perform better. The springs connecting the lever arm to the mouse trap bolt were found unfastened quite often on the first few inspection trips so that it was necessary to fasten them more securely by bending the ends of the spring around the bolt. The effectiveness of the timing device was increased considerably by changing the lever from a "pressed masonite" lever to an aluminum lever, by using only McGill (silver) mouse traps instead of the Victor (copper) mouse traps

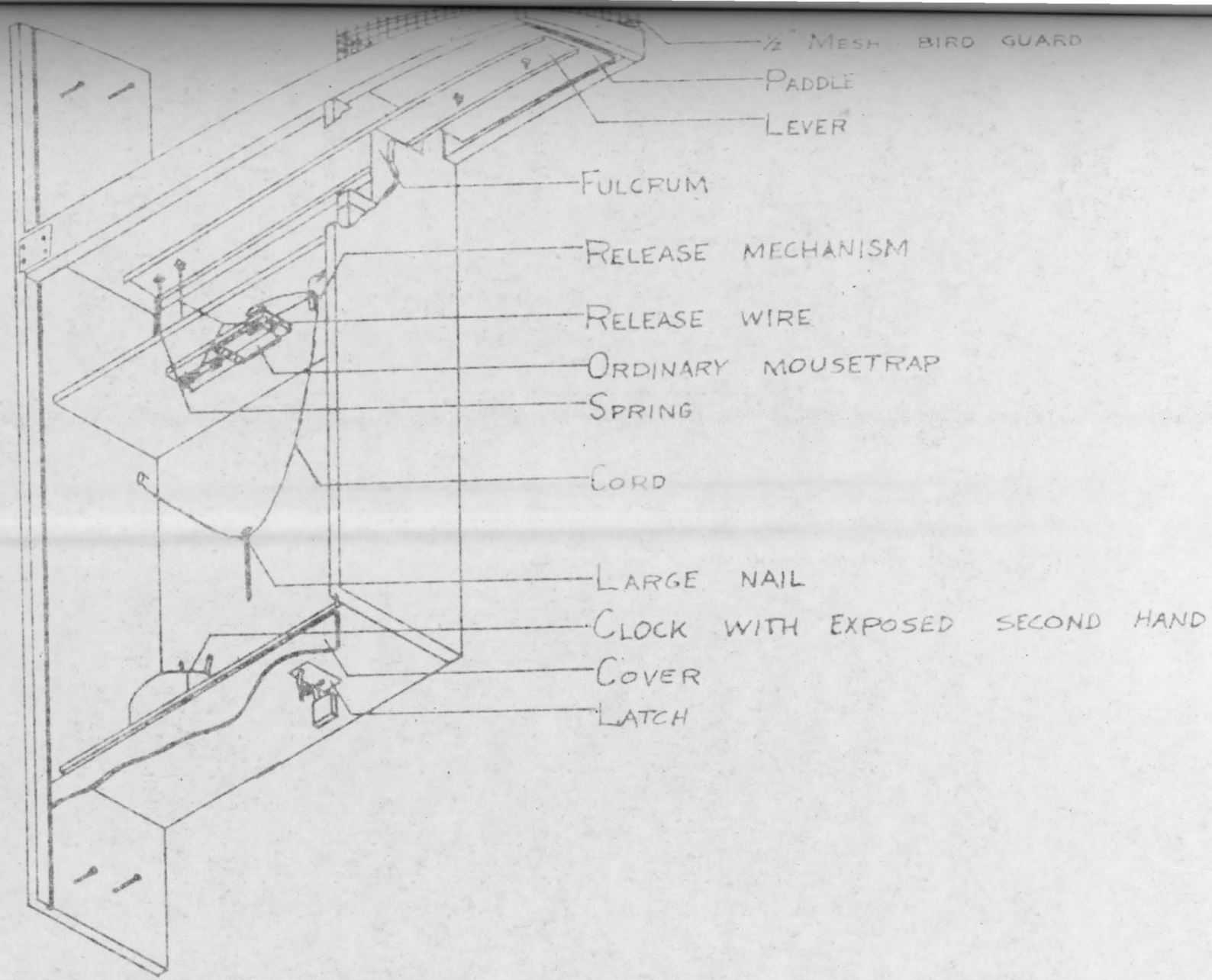


FIG. 2 HAIL TIMING DEVICE

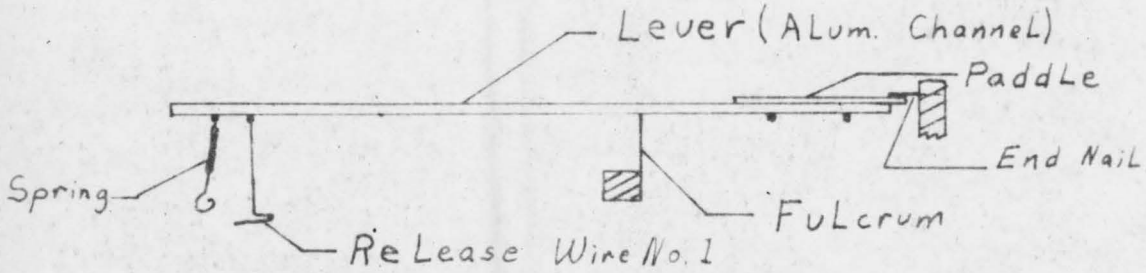


Fig. 3 The Lever

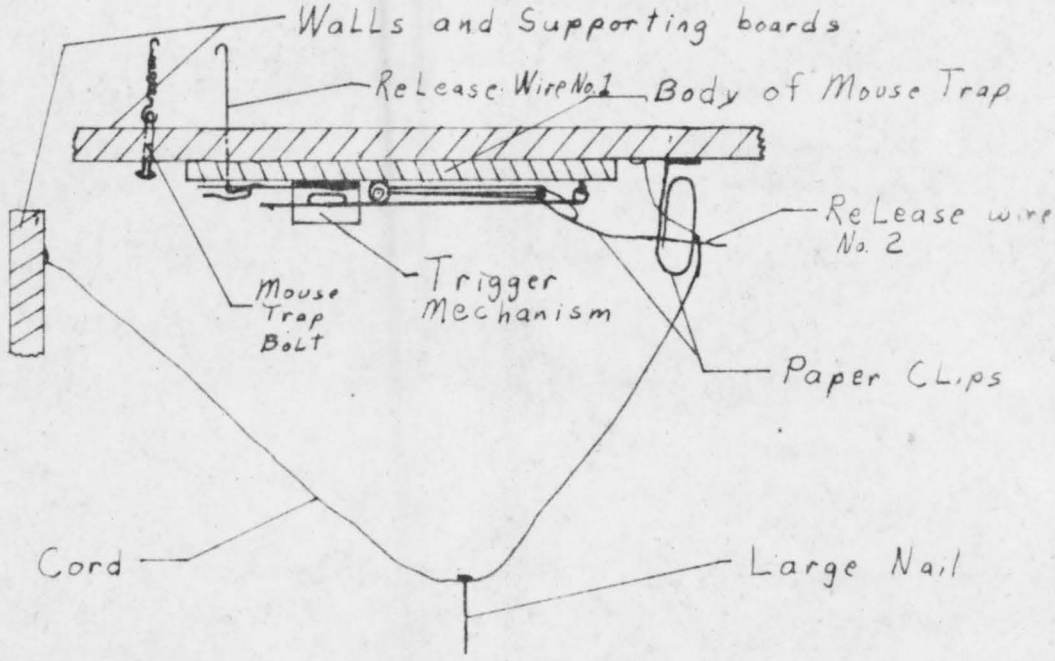


Fig. 4. The Mouse Trap

and by changing the fulcrum from that of two nails to a fulcrum made of galvanized sheet metal. A reinforcing plate made of galvanized sheet metal was added to the frame body of the timing device at the upper left hand side of the box to help keep the frame from coming apart there.

e. How they work

(1) Function of each part

When the hail stones hit the paddle shown in Figure 3, the release wire No. 1 is moved and this movement triggers the mouse trap, which springs shut and pulls apart the two paper clips shown in Figure 4, letting the cord and large nail drop down to stop to second hand on the clock below.

Each part of the timing device functions in a series of chain events, one after another, in order to stop the clock as soon as it begins to hail.

The spring attached to the aluminum lever is part of the necessary tension needed to hold the other end of the lever against the end nail and also to keep the wind from vibrating the lever and knocking it out of adjustment. The release wire No. 1 is the only link between the lever and the mouse trap and serves as part of the triggering mechanism. When the paddle is hit by hail fall it releases wire No. 1 as shown in Figure 4. The trigger of the mouse trap is very sensitive to any movement and this makes the adjustment of the trigger very sensitive.

The mouse trap relays the impulse from the release wire No. 1 to the release wire No. 2 from its holder and then the large nail and cord is dropped down into the position which stops the clock.

(2) Sensitivity and adjustments

Many adjustments can be made on the hail timing device which will change its sensitivity, but it is very difficult to make the sensitivity of each timing device the same because the physical characteristics of the timing devices are sometimes different.

The spring on the timing device was adjusted so that a lead weight placed on the lever at the tip of the end nail and weighing 80.85 grams would barely release the lever from the end nail. For the best adjustment, the end nail was made nearly horizontal with only the tip itself touching the lever. The fulcrum was situated such that the paddle was centered in its housing, and at the same time, the spring and release wire were moved to a vertical position. Another adjustment was made on the length of the wire below the mouse trap trigger so that 1/4" movement of the lever at the tip of the end nail was required to release the mouse trap.

It was decided that the large nail should hang so that it rests against the right side of the clock in a position as close as possible to the rotating hands of the clock, and this was accomplished by hanging the string from the board

above the clock right over the spot where the nail is to hang, and placing the other end of the string, without slack, in the rear of the left side about 3 inches above the bottom board.

d. Data obtained

(1) Times of first hail fall

After each hail storm, an inspection trip was made to the network to check the indicators and especially to check the timing device to obtain the clock time in hopes that the time indicated on the clock would tell the time that the first hail fell for the previous hailstorm. When the timing devices were first installed on the network, they did not work very well, but after successive adjustments were made, they began to operate better. The wind was the worst hinderance at first because the vibration of the lever and paddle triggered the mouse traps many times. Other causes for the clocks to stop were birds, heavy rain and vandals.

Table 6 lists the "Times of First Hail Fall" from the timing device as obtained from all the inspection trips made during the 1961 season of operation. To identify the location of each indicator, the indicator numbers associated with the particular timing device are recorded in Table 6.

A question mark in Table 6 indicates that the time the clock stopped may not have been the correct time of first hailfall, but rather that the clock may have been stopped by wind, vibration, birds, vandals or other causes.

TABLE 6 (Page 1 of 3)

TIMES OF FIRST HAIL FALL

Indicator#	Time*
2 May 1961	
82	7:15
90	4:25 ?
5 May 1961	
None	None
12 May 1961	
43	R
46	2:43 ?
13 May 1961	
1	9:01 ?
2	R
3	R
4	9:38 ?
5	10:48 ?
6	8:19 ?
7	5:03 ?
8	12:05 ?
9	1:14
10	7:09 ?
11	6:12 ?
12	9:13 ?
13	5:19 ?
14	R
15	7:46 ?
16	6:23 ?
17	6:18 ?
18	5:41 ?
19	3:47
20	7:04 ?
21	R
22	1:50
23	1:12
24	7:28 ?
25	9:39 ?
26.	11:51 ?
27	R
28	12:13 ?
29	1:29
30	R
31	R
32	R
33	4:57 ?
34	5:03 ?
35	4:28 ?
36	9:55 ?
37	5:21 ?
38	9:43 ?
39	11:37 ?
41	R
42	1:03
48	2:08
49	4:52
50	2:12
51	7:30 ?
52	11:54 ?
53	6:27 ?
60	7:07 ?
71	11:35 ?
90	4:07
1001	1:01 ?
1002	R
1005	2:08
1006	6:10 ?
1007	2:43 ?
1008	4:26 ?
1009	7:35 ?
1010	8:56 ?
1011	5:36 ?
1012	6:34 ?
1013	3:38
1014	4:19 ?
1015	11:53 ?
1016	8:12 ?
16 May 1961	
None	None
20 May 1961	
60	R
71	8:37 ?
82	R
1002	R
21 May 1961	
None	None
28 May 1961	
30	8:36 ?
31	8:28 ?
32	R
1011	6:00 ?
1012	8:28 ?
29 May 1961	
None	None
30 May 1961	
60	5:32 ?
31 May 1961	
76	R
2 June 1961	
1	2:13
2	2:35
3	2:39
4	2:43
5	2:49
6	R
7	12:03 ?
8	R
9	R
10	1:29 ?
11	R
12	R
13	5:20 ?
14	5:45 ?
15	R
16	R
17	8.57 ?
18	R

Table 6 (cont) (Page 2 of 3)

TIMES OF FIRST HAIL FALL

Ind. #	Time
2 June 1961 (Cont.)	
19	6:01
20	6:03
21	R
22	R
23	6:01
24	R
25	3:20
41	R
42	R
43	4:20
44	R
45	R
46	11:30 ?
47	4:58 ?
48	R
49	R
53	6:23
1005	R
1006	5:29 ?
1007	R
1008	R
1009	5:50 ?
1010	R
1011	3:31
1012	9:50 ?
1013	3:23
1014	5:28 ?
1015	3:13
1016	R
26	R
27	5:41 ?
28	3:48
29	3:49
30	3:59
31	4:04
32	1:13 ?
33	2:32 ?
34	5:30
35	R
36	R
37	5:16
38	4:20

Ind. #	Time
4 June 1961	
82	5:43 ?
90	R
5 June 1961	
None	None
8 June 1961	
None	None
10 June 1961	
1	5:12
2	5:08
3	5:19
27	5:25
28	5:35
50	5:45
51	R
12 June 1961	
None	None
13 June 1961	
None	None
24 June 1961	
27	6:00 ?
25 June 1961	
24	7:09
49	2:29
1005	2:29
1006	4:15
1007	R

Ind. #	Time
30 June 1961	
None	None
1 July 1961	
None	None
3 July 1961	
40	2:26
10 July 1961	
26	5:16
27	5:18
28	5:05
13 July 1961	
23	12:20
24	3:20
31	5:01 ?
32	5:27 ?
33	10:10
34	10:12
1006	5:05 ?
1008	R
1009	6:00 ?
1010	4:55 ?
1011	5:10 ?
1012	5:01 ?
1016	1:25 ?
14 July 1961	
2	R
3	3:06
4	3:08
5	3:09
6	3:12
7	3:13

Table 6 (Concluded)

TIMES OF FIRST HAIL FALL

Ind. #	Time
14 July 1961 (Cont.)	
11	11:47 ?
12	1:43 ?
13	R
39	2:50 ?
41	R
42	4.49
48	3:42
49	3:37
50	R
51	R
52	3:29
1003	R
1004	3:20
37	11:44 ?
20 July 1961	
40	R
25 July 1961	
60	4:55
26 July 1961	
26	3:41 ?
27	11:32 ?
28	9:10
29	5:37 ?
30 July 1961	
8	R
9	R
10	R
11	5:07
12	9:18 ?
26	R
27	5:28 ?
28	3:15 ?
29	10:51 ?
30	R
31	R
32	R
33	3:15 ?
34	R
43	R
1005	R
1013	R
12 Aug. 1961	
8	R
12	2:38
14	3:00
17 Aug. 1961	
None	None

* A question mark (?) signifies that the time indicated may not be the time of first hailfall. An "R" indicates that the clock was still running when inspected.

Times when the timing devices were not tripped (even though hail stones fell at that location) are indicated with an "R" to indicate that the clocks were still running when inspected.

Examination of Table 6 shows that at the first of the season difficulty was experienced with the timing devices, but later in the season a better record was obtained for the "times of first hail fall."

All the times shown in Table 6 were taken from the "Hail Indicator Data Sheets" which were the data forms used on inspection trips to record the field data. Table 1 shows how this data was recorded along with the associated indicator data.

A "Clock Calibration Form," Table 7, was maintained for each clock while in use on the network and also before they were placed in the timing devices. Table 7 shows how the data were recorded and how well a typical clock kept time. The plus (+) mark in the remarks column indicates that the clock was adjusted to run faster, and a minus (-) mark indicates the opposite, while a zero (0) mark indicates that no adjustment was made. The data in Table 7 were collected before the clock was placed in a timing device while the clocks were being calibrated in the laboratory, but this sample also illustrates how the data was kept in the field.

Table 7. CLOCK CALIBRATION FORM

Clock No. 86

1961 Date	CSU Std. Time	Actual Clock Time	Time Error Fast	Time Error Slow	Remarks
6 Apr	10:18	10:18	0	0	0
7 "	09:00	09:00	5 sec		0
10 "	10:16	10:16	10 sec		0
11 "	11:13	11:13		5 sec	+
12 "	10:14	10:14	8 sec		−
13 "	9:19			13 sec	0
17 "	10:21	10:21		22 sec	0
19 "	10:29			12 sec	+
21 "	10:48		8 sec		0
25 "	9:47		23 sec		0
28 "	8:59		8 sec		0

e. How the data were used

(1) Times plotted on network map

The "Times of First Hail Fall" were plotted on network maps for each day of hail fall during the 1961 hail season. These maps, as illustrated in Figure 5, are useful in tracing the storm movement; in determining the rate of movement, to verify the times from the mailed-in-reports, and especially to determine the specific times of first hail fall as the storm moved over the network. Figure 5 shows the "Time of First Hail Fall" at indicators 1 through 5. This sample from the 2 June storm shows that the storm was moving from the NW to the SE as the arrow indicates. The "Time of First Hail Fall" at indicator number 1 occurred at 2:13 and at indicator number 5 at about 2:49, the amount of time in between being 26 minutes. This indicates that the storm moved approximately 8 miles in about 26 minutes, or about 18 m.p.h.

Similar maps are being prepared which show times of hail fall from the timing devices and also from reports from cooperative observers.

3. Hail Collection Boxes

(In separate report)

4. Technical Stations (In separate report)

a. Jennings sorter

b. 8 mm camera

c. Ice nuclei counter

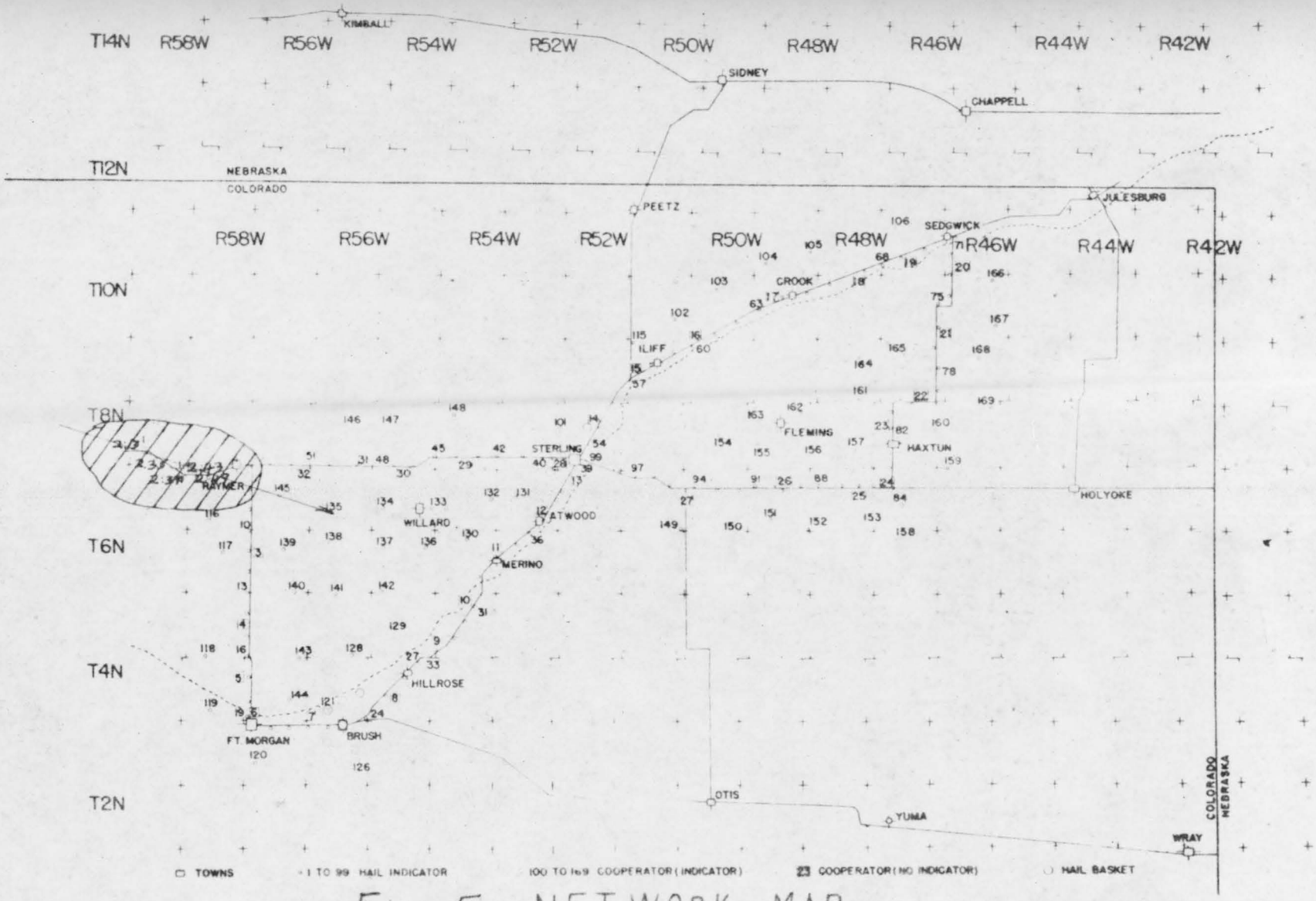


Fig. 5. NETWORK MAP

2 June 1961

B. Studies of Hail at the Ground (by C. Thomas)

1. Network

a. Cooperative observers

(1) Ratings

The cooperative observers were graded by the field representatives on how well they performed their duties as a cooperator. The duties of the cooperators were associated with the instruments they had such as the indicator, timing device, cold boxes and the mailing in of data.

In 1960, Jeris Danielson, as field representative, graded the cooperators on the basis of their efficiency and interest.

Jim Lake and Larry Eaton were the field representatives for the 1961 season. They made ratings of the cooperators and these two ratings (along with the 1960 rating) are given in Table 8.

(2) Card system list of names

A list of names is kept in card filing cabinets and names are divided into categories A, B, and C.

Category A consists of:

(a) Two hundred and nineteen names obtained from county agents in the spring of 1959,

(b) Fifty-two names of the Northeast Colorado Hail Suppression Association (NECHSA) directors which were obtained from Bob McCaffree in 1960,

(c) Fifty-four names of persons personally contacted by Richard A. Schleusener in May 1959, who were requested to send reports of rain and hail, and

(d) Thirty-three names of persons personally contacted by Richard A. Schleusener in the spring of 1960.

Category B consists of:

(a) Names of personal contacts by Joris Danielson, including those accepted indicators and/or hail baskets, and

(b) Names of individuals who contributed to research equipment in the spring of 1961.

Category B consists of 59 names.

Category C consists of a list of names from L. O. Grant. This list consisted of 61 names of people who were first contacted by Joris Danielson during the summer of 1960, and this list duplicates in part category "B".

Categories A and C are the mailing lists used for mailing with which information to cooperators. Category B was not included because most of the names in Category B are also in category C.

(3) What instruments they had

Many of the cooperators had instruments with which to gather data. Table 8 lists those cooperators who have or have had an instrument of some kind, and also listed is the mailing address, location, and information telling what instruments they had.

(4) What was mailed to cooperators

(a) Newsletters

Newsletters were sent to the cooperators to tell them about the progress being made in our study of the characteristics and formation of hail. Figures 6 and 7 are the two newsletters sent out during the 1961 season. Newsletter one was sent out in April and newsletter two was mailed in August.

(b) Forms

Forms are sent to the cooperators so they could enter their data on these forms and send the forms back to the project.

Figures 8 and 9 are the forms mailed to them on which they recorded rainfall amounts and hail occurrences and gave associated data as asked for on the forms.

Figures 10 and 11 are the letters which accompanied the forms that were mailed to them as indicated in the "Enclosures" of each letter.

The "Report of Hail Occurrence" form, Figure 9, has a space where the cooperator may indicate whether or not he is out of forms. When he indicates he is out of reporting forms, the letter shown in Figure 11 was sent to him with four envelopes and four hail reporting forms.

Amount of HAIL ACCUMULATION:

Ground covered 1 5 10 25 50 75 per cent

or Ground covered 100 per cent and _____ inches deep

Maximum WIND VELOCITY accompanying hail

- ☐ 3 Gentle breeze (Leaves and small twigs in constant motion
- ☐ 5 Fresh breeze (Small trees begin to sway)
- ☐ 8 Fresh gale (Breaks twigs off trees)
- ☐ 10 Strong wind (Trees uprooted or broken, some structural damage)
- ☐ 12 Severe wind (Widespread wind damage to trees and buildings)

Estimates of CROP DAMAGE

Wheat 1	Per cent damage _____
Corn 2	Per cent damage _____
Sugar Beets 3	Per cent damage _____
Other 4 _____	Per cent damage _____

Remarks:

Did you save any hail stones from the storm? Yes _____ No. _____

About how many do you have? _____

Other Remarks: (Such as shape of stones, direction of storm movement, etc.)

Do not write below this line

Ident	Location									Date			Time	
	X	Y	NE	SE	NW	SW	S	N	W	Yr	Mo	Da	Begin	Dur

10 20 30

S			Prec	Cover		Wind	Crop Damage										E
S	MC	L		Amt.	Dp	Bf		%			%			%			
							1			2			3			4	

40 50 60

FIGURE 7

wsletter No. 2 1961 Season

STUDY OF THE CHARACTERISTICS AND FORMATION OF HAIL

lorado State University Fort Collins, Colorado

ar Cooperator:

our hail research program for this summer nears completion, I want to tell you out the progress of our studies.

st of our time has been spent in collection of data on the hailstorms of 1961. me of the highlights are the following:

12 and 13 May - Widespread damage from hail, followed by a late-season snowstorm.
2 June - Severe damage in eastern Weld County.
19 June - Severe damage in Larimer and Weld Counties (Note: Hail storms are no respecters of persons -- in this storm there was 100% crop damage to wheat on the farm of Lew Grant, Assistant Researcher on the hail project. Lew is a week-end farmer on a quarter section southwest of Hudson.)

Airplane flights for data collection: Airplanes from the U.S. Weather Bureau flew missions over NE Colorado on 16 and 24 May. On both days, 3/4" hail was reported in northeastern Colorado. Planes included a B-57, a U-2, 2 DC-6's, a B-26 and a B-47. On 13 and 14 July Dr. F. Bates from the University of Kansas flew his C-45 in NE Colorado. On 14 July he was flying near New Raymer and obtained data on a hail-producing cloud concurrently with our stereo cameras located near Fort Collins.

Stereo cameras were operated from near Fort Collins for 10 separate days with hail.

Radar data: The leased set located at New Raymer has tracked 440 separate echoes between 15 May and 21 July.

Visitors to the project: Glenn Stout, hail researcher from Illinois visited on 14 July. Loren Crow, consultant from Denver, visited on 2 separate days (and viewed with me the "lake" of hail stones that accumulated north of New Raymer near Miss Laura Best's ranch on 6 July). Dr. Soulage, ice nuclei expert from French observatory Puy du Dome, is scheduled to visit in September.

ur field studies for this summer will end on 15 August 1961. However, please ontinue your reports through 31 August, and mail us your rainfall reports by September 1961.

hanks for your help on this summer's project.

Sincerely yours,

Richard A. Schleusener

Richard A. Schleusener
Associate Research Engineer

August 1961

FIGURE 8. RAINFALL RECORD FORM

RAINFALL RECORD FOR MAY 1961

Name_____ Mailing Address_____

Legal Description_____ $\frac{1}{4}$ S_____, T_____N, R_____W

Instructions: (1) Record rainfall amount each day, and (2) draw a circle around any date on which hail occurs, and in addition, send in a "Hail Report".

1_____				
2_____	8_____	14_____	20_____	26_____
3_____	9_____	15_____	21_____	27_____
4_____	10_____	16_____	22_____	28_____
5_____	11_____	17_____	23_____	29_____
6_____	12_____	18_____	24_____	30_____
7_____	13_____	19_____	25_____	31_____

Type of gage_____ Approximate diameter ____ inch

FIGURE 9

REPORT OF HAIL OCCURRENCE

(PLEASE FILL OUT COMPLETE REPORT)

INSTRUCTIONS:

1. Please fill out one of these forms for each hail occurrence at your home, no matter how small the hail stones.

2. Mail completed form immediately to the Civil Engineering Section, Colorado State University, Fort Collins, Colorado; using the attached self-addressed envelopes.

3. If you cannot give all the information requested, please send us as much information as possible. Any information is helpful to us.

Name _____ Mailing Address _____

(Please print)

Check here if you have no more reporting forms ☐

DATE of storm: _____

Exact LOCATION of hail occurrence: 1/4___, Sec.___, T___N, R___W.

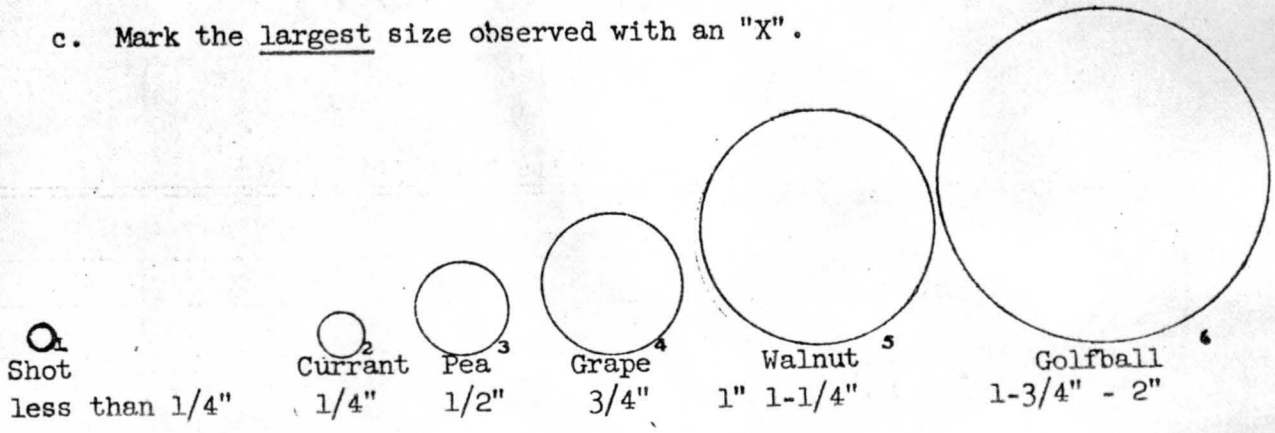
TIME hail began_____ a.m. p.m. Hail lasted_____minutes

Indicate size distribution of hail

a. Check (✓) smallest stone observed.

b. Circle the size of stone that was most common.

c. Mark the largest size observed with an "X".



If larger than golfball, estimate diameter in inches_____.

Total PRECIPITATION accompanying hail: _____inches.

(PLEASE FILL OUT THE BACK OF THIS REPORT)

FIGURE 10. Letter requesting hail and precipitation data from cooperative observers.

COLORADO STATE UNIVERSITY
Fort Collins, Colorado

CIVIL ENGINEERING DEPARTMENT

Dear Cooperator:

Please help us in our hail research studies for 1961. You can help us by doing the following:

1. Reporting hail occurrences on the enclosed REPORT OF HAIL OCCURRENCE form. As indicated on the instructions, one of these forms should be filled out and mailed to us after each hail occurrence.

2. Collecting hail stones during a storm. Pick or scoop up hail stones from a soft surface such as a lawn as soon as possible after they have fallen and keep them in a waxed or plastic container in your freezer or freezing compartment of your refrigerator. If large or unusual stones occur, it would be appreciated if a few were wrapped individually in aluminum foil or waxed paper before storage. Please indicate on the back of the REPORT OF HAIL OCCURRENCE form when you have collected some stones. We will attempt to pick up the stones you save within a week.

3. Reporting rainfall amounts. Please keep a record of the rainfall you receive at your home each day on the enclosed card during the month of May, and mail it in one of the enclosed envelopes by 5 June 1961. We will mail cards to you later for June and July.

Information on hail research for 1961 is given in the attached Newsletter.

Thank you for your help.

Richard A. Schleusener
Assistant Research Engineer

RAS:mf
Enclosures:
1. Newsletter No. 1, 1961
2. Hail Reporting Forms (4)
3. Envelopes (4)
4. Rainfall Record - May 1961

FIGURE 11. Letter sent to cooperators who had used all of their reporting forms.

COLORADO STATE UNIVERSITY

FORT COLLINS, COLORADO

Department of Civil Engineering

Dear Cooperator:

Thank you for sending us reports of hail occurrences this summer. Your reports are most helpful in our study of hail and severe storms in northeastern Colorado.

I am enclosing additional envelopes and reporting forms for you to use in case of further hail storms this summer. Please continue to send us reports as you have been doing in the past.

Thank you for your help.

Sincerely yours,

Richard A. Schleusener

Richard A. Schleusener
Assistant Research Engineer

Enclosures:
4 Envelopes
4 Hail Reporting Forms

(5) How their data are processed

(a) Precipitation reports

The rainfall amounts as recorded on the mailed-in precipitation reports are plotted on a network map in red with the U.S. Weather Bureau's Cooperative Observer amounts which are plotted in blue. Figure 12 shows how these rainfall amounts are plotted and also shows the symbols indicating the source of the value. Values plotted with a circle around them are precipitation amounts which were accompanied by hail according to the "Rainfall Record" mailed in by the cooperator. Values with a square around them are precipitation amounts accompanied by hail according to the mailed-in hail report of the cooperator who sent the precipitation amount in on his hail report.

Using the precipitation amounts in Figure 12, an overlay map can be used to draw the isolines of precipitation amounts as shown in Figure 13. Isolines are drawn for 0.10 inch, 0.25 inch, and multiples of 0.25 inch.

(b) Hail reports

Hail reports are mailed in on the form shown in Figure 9, part of which is plotted on a network map as shown in Figure 14. Each circle on the map indicates that there was a mailed-in report received from a cooperative observer who lives at that location on the

Fig

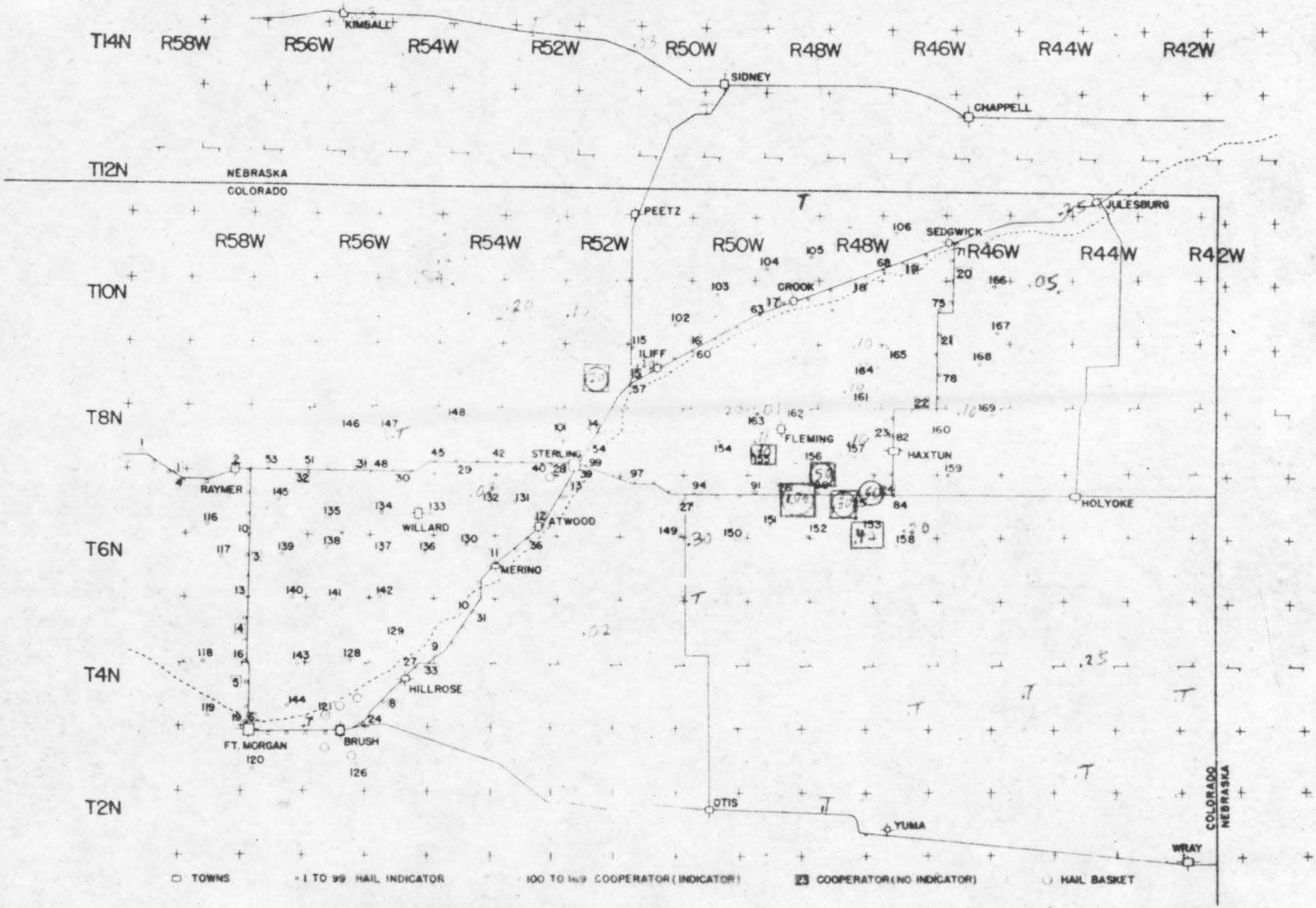


Fig. 12 Precipitation amounts

2 MAY 1961

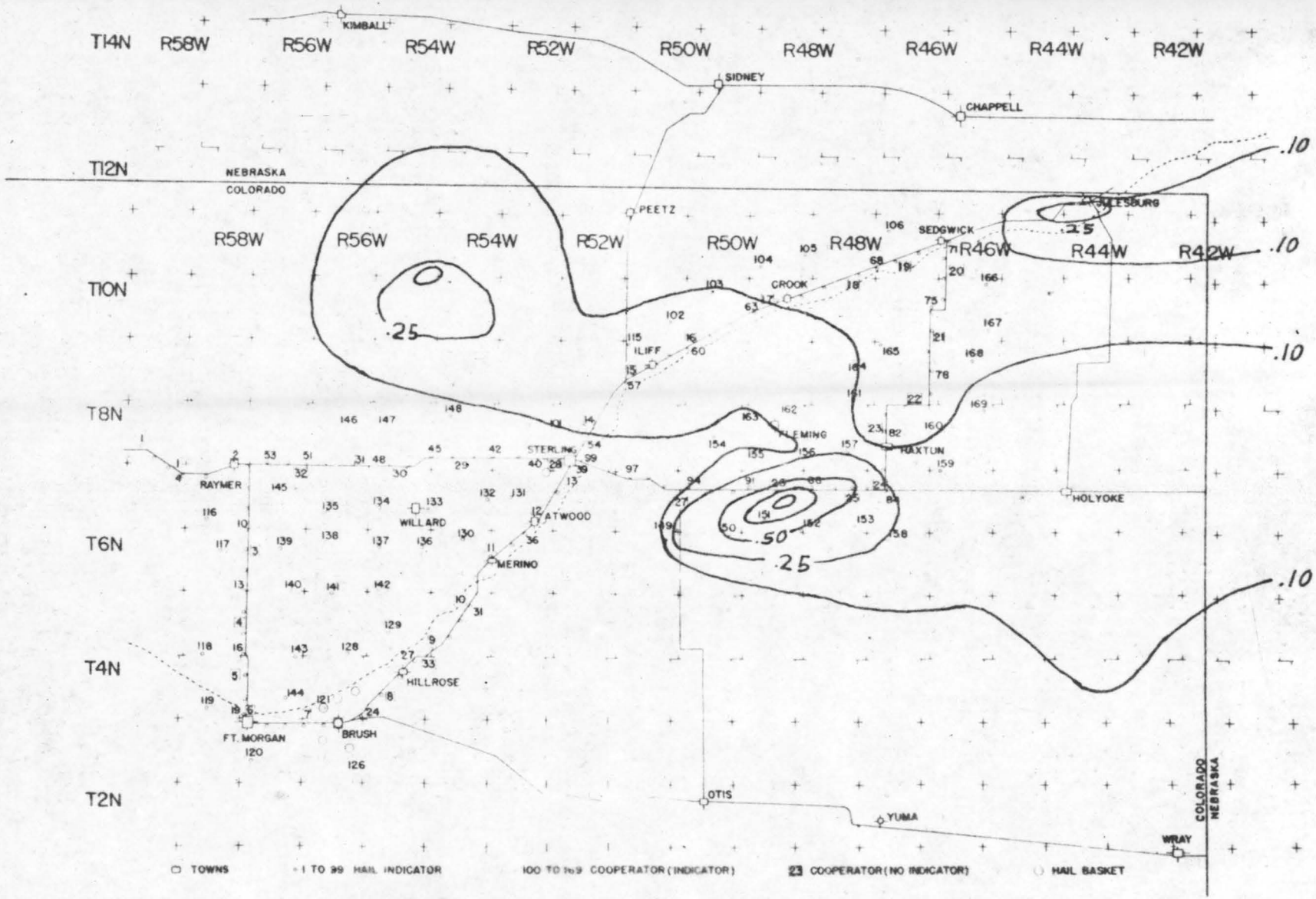


Fig. 13 Iso-lines of precipitation amounts plotted in Figure 12.

2 MAY '61

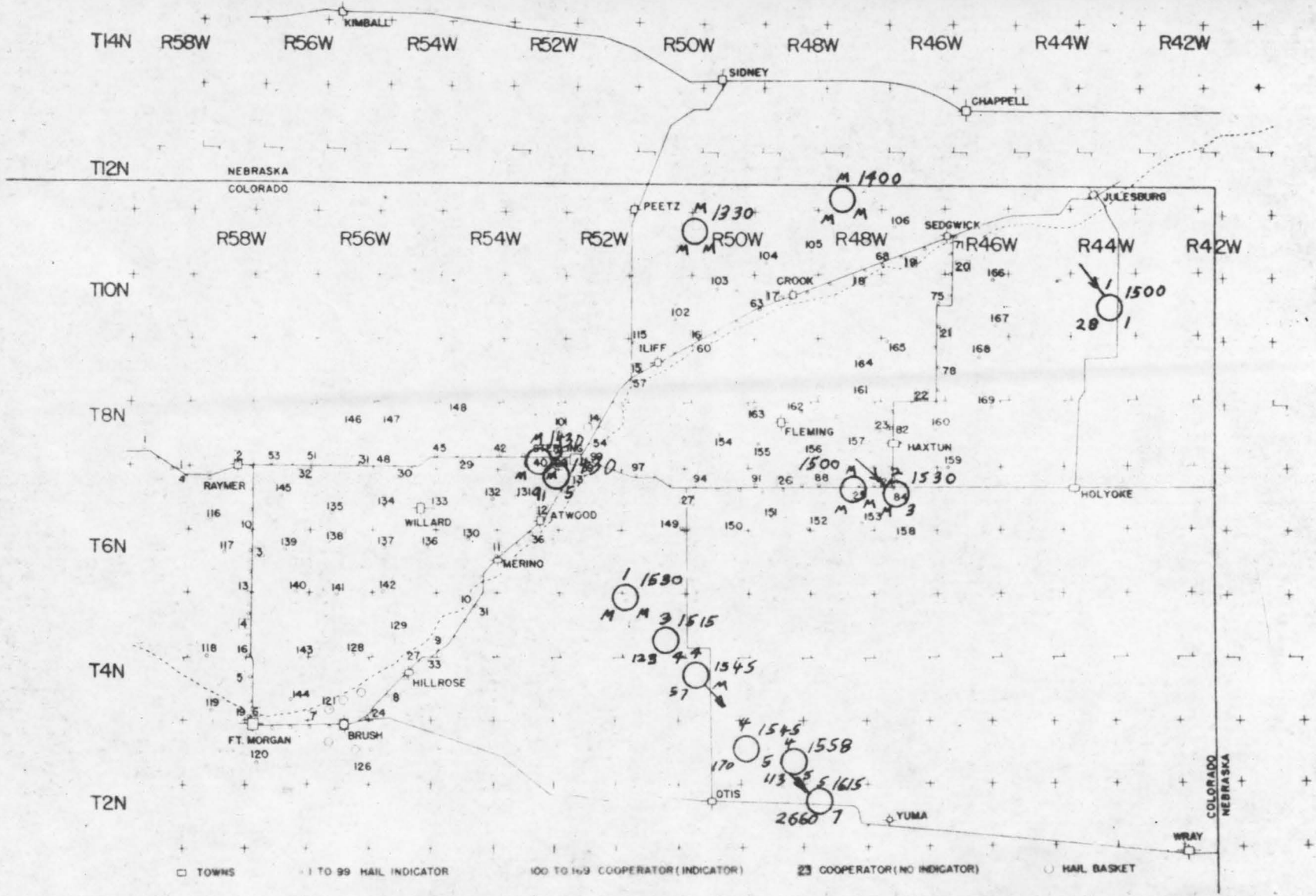


Fig. 14 Hail reports plotted on network map.

1 JULY '61

map. The number above the circle refers to the coded number of the most common stone size (see Figure 9 for the size code). The number on the lower right refers to the coded number for the largest stone size, and the lower left number indicates the energy number estimated for that particular hail storm. When data are not available, an "m" is recorded to indicate "missing" data. Also shown are the times of first hail fall and the direction of the storm movement as recorded by the cooperative observer. When all the cooperator reports for one hail data are plotted on the network map, the movement and intensity of the storm can usually be determined.

The time of first hail fall as taken from the mailed-in hail reports were plotted on network maps as shown in Figure 15 along with the duration of the hail storm in red ink. Also plotted with these mailed-in times were the timing device times as shown in Table 6, but the sample in Figure 15 has none of these times plotted because there were none on 1 July 1961. The timing device times were plotted in green ink.

(6) Analysis

Statistical data involving the "Frequency of Hail," "Hail Paths," "Hail Onset and Duration," "Percent of Ground Covered by Hail Fall," and "Maximum and Most [illegible]

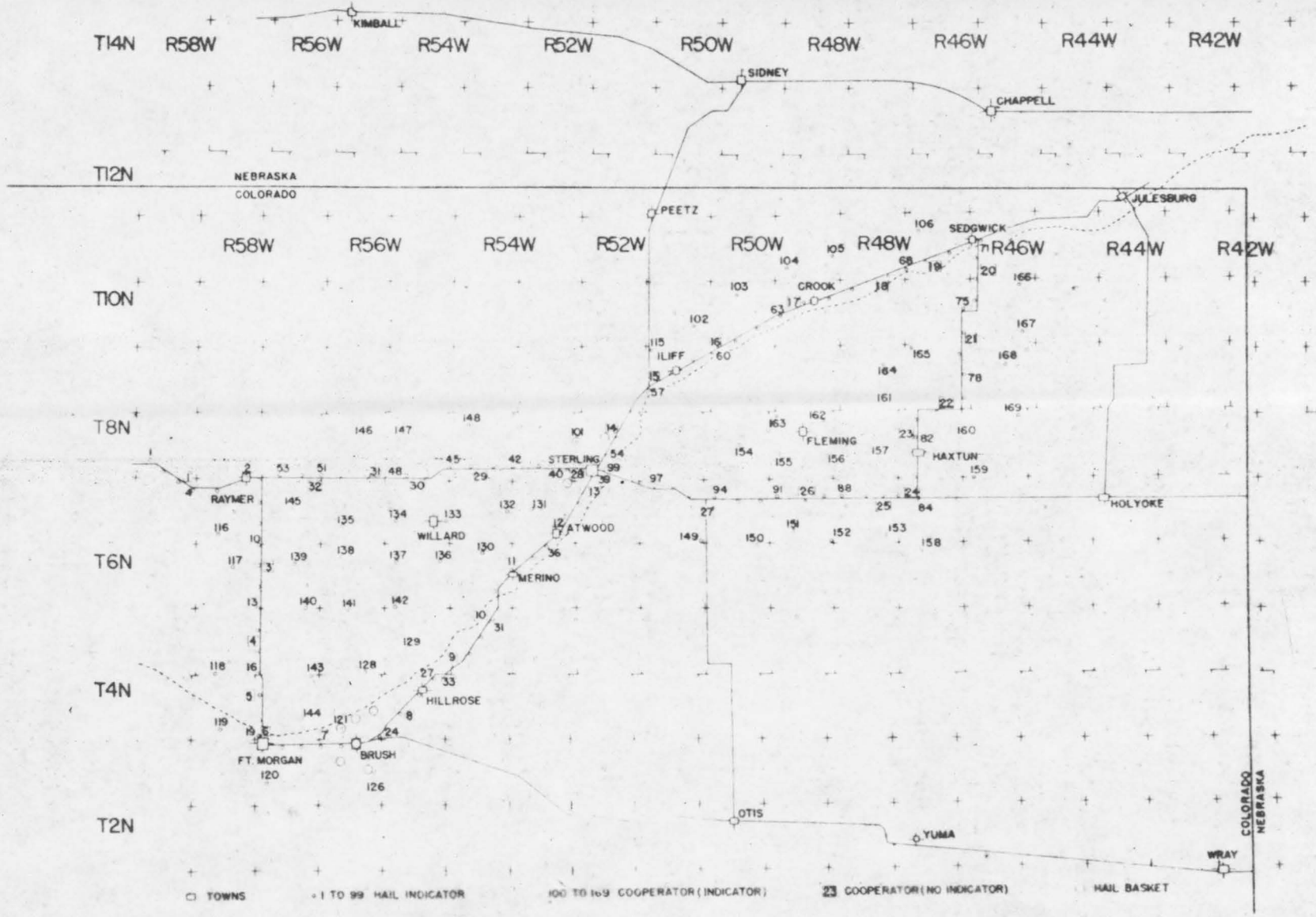


Fig. 15 Times of first hailfall, and duration of hailfall.

1 July 61

146

Common Stone Sizes," were analyzed. The results were used to show the characteristics of hail storms.[1]

b. Special notes on cooperative observers from a field trip by Schleusener and Grant in September 1961.

In New Raymer, we talked to Mr. Walker from whomwe had rented the house. We made arrangements to pick up items of furniture which had been left there during the summer. Three bunks are to be brought into Fort Collins by about 1 November 1961 by the two individuals from Fort Collins who are presently renting the house.

We checked with Mr. Barker who is head of the town council and asked him about payment of a lease fee for the radar site. He told us we were welcome to the use of the site at no cost and that he would be very happy to have Tom Henderson come back to New Raymer next summer.

We visited with Mr. John Bloedorn and Mr. H. Schug at the Farmers State Bank in Fort Morgan. We reviewed with them the preliminary results of the 1961 season as outlined in the paper to be presented at the Kansas City Radar Conference. They believe that the 1961 hail damage in Fort Morgan was less than that in 1959 or 1960.

We also reviewed the same data with Mr. Arlie Rudel in Sterling.

---

[1] Schleusener, Richard A. and Lewis O. Grant: "Characteristics of Hailstorms in the Colorado State University Network, 1960-1961," presented at the Ninth Weather Radar Conference, October 1961.

I called Gail Heimann at the Security State Bank in Sterling. Gail is leaving as of 1 October to be vice president of a bank in Arvada. He stated that he would make arrangements so that funds could be paid from the Northeast Colorado Hail Suppression Association on the signature of Arlie Rudel only after he leaves on about 1 October. I told him that I would send him a billing for the cold box as soon as it arrives at Colorado State University.

Following is a description of the individuals that operated cold boxes for us in the summer of 1961 in the order in which we visited them on this trip.

117. Mrs. Frank Wulf (Grade: B). The box was on a concrete slab southwest of the shop with the cord running to the southwest door of the shop. The shop was located about 50 yards south of the residence. Mrs. Wulf appears to be the one who does the reporting.

No. B William Kroskob (Grade: B). The cold box was located about 10 yards southeast of the garage with the power cord being strung overhead from the garage to a light pole. The power cord was left on the pole at this location.

143. Marvin Kemball (Grade: A+). Mr. Kemball is a young man and appears to be aggressive and very interested in the problem of hail. The box was placed northeast of his shop which is about 25 yards northeast of his residence. He estimates that

the box ran about one-third of the time. The box had about one-eighth inch depth of water in the box from three and one-half inches depth of rain that occurred in August. Mr. Kemball used his own cord to connect the box.

Unit C. Mr. Elmer Reickers (Grade: B+). This box was located about 10 feet east of a chicken house which was about 50 yards east northeast of the residence. The box had been disconnected as per the instruction given by the Newsletter No. 2 for the 1961 season.

102. Jim Kippes (Grade B-). The cold box was located about 100 yards north of the residence, and was connected into a farm labor house. Mr. Kippes is about 45 years old, aggressive, and appears quite interested in the project. He has several sons at home of high school age.

164. Miss Linda Yost (Grade: B). The cold box was connected to a pump pit under a windmill east of the residence. Linda is 14 years old and a freshman at Haxton High School. She appears to have done a good job in sending in reports for the season.

107. Alvin Otsuka (Grade: A). This cold box was connected northwest of the garage through the north garage wall. The garage is located west of the residence. Alvin is a high school student in Sedgwick.

167. Harold Woodhams (Grade: B). The box was connected into a pump pit 10 feet northwest of a windmill, located about

50 yards southeast of the residence. Mr. Woodhams is about 55 years old, talks in a rather slow manner, and keeps a very neat farmstead. He suffered damage from a tornado in June of 1960.

160. Mr. William Jeffers (Grade: A). This box was connected to a machine shed about 75 yards northwest of the residence. Mr. Jeffers is a retired farmer and very interested in the program and wants to help next year.

153. Mr. Fred Fetzer (Grade: A). The cold box was located near a gate to a field south of the house. The power cord was connected to the south wall of the garage. Mr. Fetzer is about 55 years old and has a slight foreign accent.

Unit D. Mr. Dean Brown (Grade: A). Mr. Brown was not home at the time of our visit. The box was located southwest of the garage about 50 yards southwest of the residence. Mr. Brown's residence is surrounded by a large number of pine trees.

132. Mr. William Phillips (Grade: C). The box was located about 20 yards southeast of the residence with the power cord connected to the door of the garage which was locked. We talked to Mrs. Phillips who was quite elderly. Evidently Mr. Phillips had made a commitment to take care of the equipment and Mrs. Phillips ended up being the one responsible for it. They had attempted to turn the box on and off depending upon whether or not many storms were forecast for the area and had considerable difficulty with it for that reason. They would prefer that they not be asked to assist in another year.

147. Loren Kirschner (Grade: A). The box was connected northwest of a metal machine shed about 50 yards east of the residence. Mr. Kirschner had been an active member of the Northeast Colorado Hail Suppression Association. He feels that the box might be located in a better location other than his residence because in 15 or 20 years of farming he has never had severe hail damage and feels that there is some reason for this, probably because of terrain features in his immediate vicinity.

138. Mr. Gus Anderson (Grade: A). The box was located behind the house about 10 yards north of the residence. Mr. Anderson is about 45 years old, small, wiry, and interested in the hail project. He suffered severe hail damage in 1961.

We visited with Mr. Warren Propst, who had flown for Tom Henderson during the 1959 Hail Suppression Project. We asked Warren about his opinion on the feasibility of flights into thunder storm areas. His opinion was that flights into the fringes of some thunder storms would be feasible, but that it would probably not be feasible to plan on flight through the hard core of the larger thunder storms. He requested that he be placed on the mailing list for our reports. His address is, Warren Propst, Atwood, Colorado.

We also attempted to visit with Mr. Tom Pomeroy of Atwood, but he was not home at the time we stopped there.

c. Instruments

The instruments were either those maintained by the cooperators or those maintained by the field representatives.

Table 8 shows the location of the sixteen cold boxes, the sixty (60) indicators, and seventeen timing devices used by the cooperators during the 1961 season. In addition to the timing devices used by cooperators, seventy three (73) timing devices were placed with the indicators on the main routes of the network. All 53 indicators on the west triangle were accompanied by a timing device as were the 15 indicators on the "cross" of the west triangle. A timing device also accompanied five (5) of the forty-six (46) indicators on the east triangle of the network. All the cold boxes and timing devices were added to the network in 1961. The entire network included cooperators, about 90 timing devices, 174 indicators, and 16 cold boxes.

(2) Hailstone studies (by Larry Eaton)

In separate report.

(3) Small drops (by Jim Lake and Ed Ellis)

In separate report.

C. Environmental Studies

1. Pibal at Sterling, Colorado

Pilot balloon observations were taken daily by Mr. Bob McCaffree at Sterling, Colorado, using a 30 gm. balloon and a single theodolite. The field observation consisted of reading the azimuth and altitude angles to the balloon at intervals at one minute from time of release, until the balloon disappeared from sight. Observations were taken from 2 June 1961 through 16 August 1961.

To reduce the data, it was first necessary to obtain the horizontal distance to the balloon. This was done by using "Tables for Computing Horizontal Distance of Pilot Balloons," printed by the U.S. Department of Commerce, Weather Bureau. When the azimuth angles and horizontal distances are known, a plot of the horizontal projection of the balloons path may be made at one minute intervals on an aerological plotting board. The average wind velocity is then measured on the board and wind direction read.

Profiles of wind direction and of velocity were then plotted against height (feet m.s.l.) for each observation.

Maximum heights obtained from each observation were listed in Table 9.

2. Radar

A 3.2 cm weather radar set was operated at New Raymer, Colorado, between 15 May and 15 August 1961. This radar set was operated by Mr. Thomas J. Henderson, President of Atmospherics, Inc., of Fresno, California.

Details of the operation of this radar set are given elsewhere.*

a. Time-lapse photographic equipment at the radar site (by Lorin Blandin)

The time-lapse photographic equipment consisted of (1) a power supply, (2) a timer unit, (3) a 16 mm camera mounted to photograph the radar scope, and (4) a 16 mm camera mounted outside the radar trailer for photography of cloud formation.

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*Schleusener, Richard A., and Thomas J. Henderson. Hail Genesis Areas in and near Northeastern Colorado. Prepared for the Crop-Hail Insurance Actuarial Association. CER61RAS58.

DATE	HEIGHT	DATE	HEIGHT	DATE	HEIGHT
JUNE 2, 1961	6620	JUNE 27, 1961	12650	JULY 26, 1961	21650
3,	5330	28,	31850	27,	23450
4,	7250	29,	31250	28,	47450
5,	8450	30,	5330	29,	10250
6,	7250	JULY 1, 1961	34250	30,	7250
7,	13250	2,	33650	31,	5990
8,	15650	3,	34250	AUG. 1, 1961	13850
9,	13250	4,	39650	2,	13850
10,	18250	5,	12650	3,	16250
11,	6620	6,	34850	4,	32450
12,	20450	7,	4670	5,	19250
13,	19250	8,	7850	6,	27050
14,	5990	9,	8450	7,	27050
15,	5990	10,	12050	8,	5330
16,	15050	11,	–	9,	30650
17,	22250	12,	16250	10,	7250
18,	19250	13,	–	11,	
19,	15050	NO OPERATION		12,	23450
20,	17450	14 JULY THRU		13,	31,250
21,	12650	20 JULY		14,	29450
22,	18050	21,	12650	15,	7250
23,	13850	22,	14450	16,	5990
24,	18650	23,	14450		
25,	11450	24,	18050		
26,	11450	25,	19250		

Table 9. Maximum height (ft. msl.) of daily pibal at Sterling, Colorado, 2 June - 16 Aug 61.

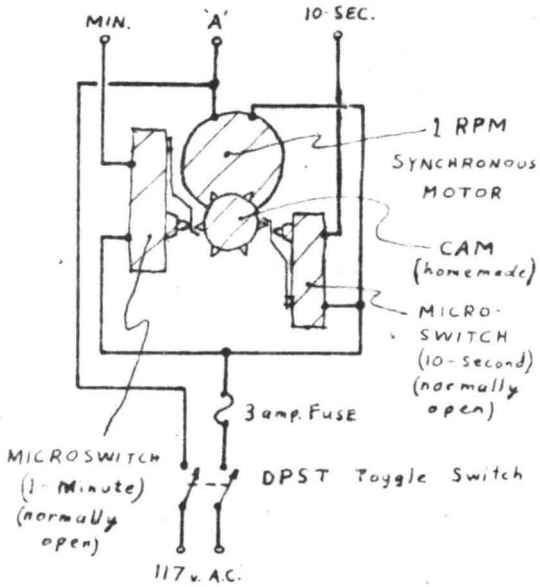
The purpose of the time-lapse equipment was to take simultaneous time-lapse photos of the radar scope and a portion of the actual clouds being observed by radar. The timer unit was used in connection with solenoid-operated 3-digit counters to record the time (to the nearest 10-seconds) of each photo. By using time-lapse photos, several hours of cloud development can be studied in minutes.

(1) Power supply

The power supply provides (a) 5.5 v. D.C. to operate the solenoid which actuates the shutters of the cameras, and (b) 7 v. A.C. to light the counters. The power supply is mounted in a 3" x 6" x 6" metal box. (See Figures 16-18) for schematic diagram.)

(2) Timer unit

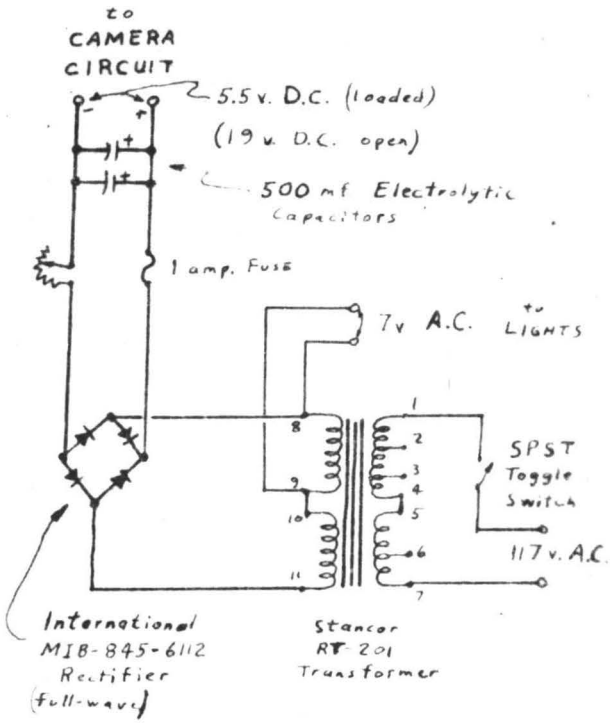
The timer unit provides 117 v. A.C. pulses to advance the 10-second and 1-minute counters. This is done by means of a 1 RPM synchronous motor which rotates a 2-level cam. The upper level of the cam contains 6 equally spaced lobes which trip a normally-open microswitch, thus sending a pulse once every 10 seconds to the solenoids of the 10-second counters. When activated, these solenoids advance the counters one digit. The lower level of the cam contains only one lobe, which trips another normally-open microswitch to advance the one-minute counter. (See Figure 17)



TIMER UNIT

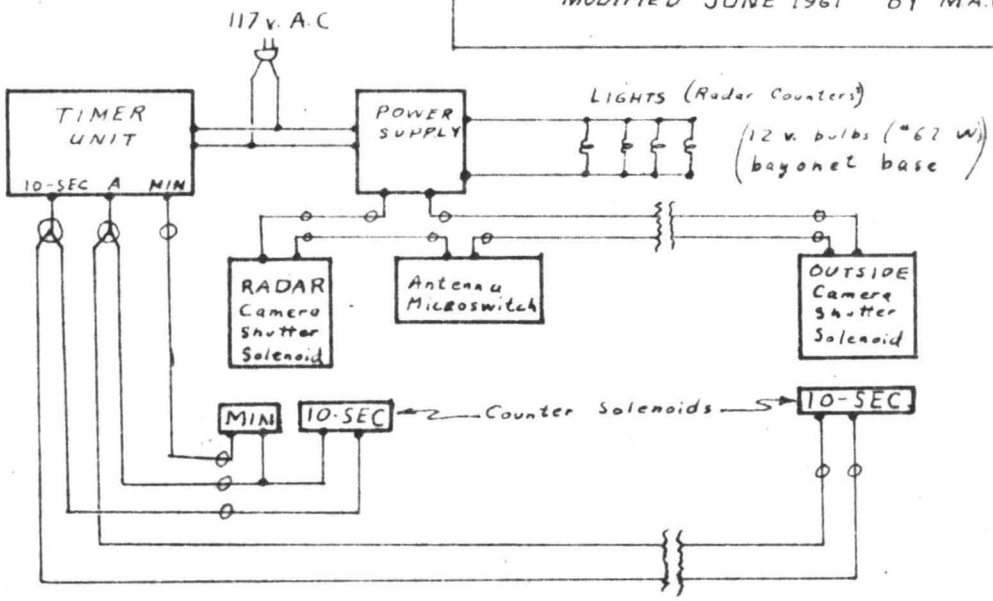
FIG. 17

BUILT BY M.A.VACHTOR JUNE 1961



POWER SUPPLY
for radar camera equipment
FIG. 16

BUILT BY TOM HENDERSON
MODIFIED JUNE 1961 BY M.A.V & L.B



⊗ - 3-way Connector (Whitaker #876)
⊖ - 2-way " (" #877)
} USED WITH Whitaker #864 Ends
(Purchased from Hendrie & Bolthoff)

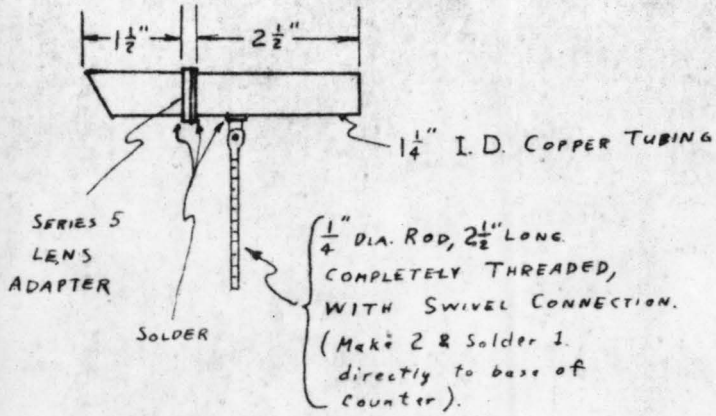
INTERCONNECTION DIAGRAM
for radar accessory equipment
FIG. 18

CSU PROJECT 2445 DRAWN BY L.B SEPT. 1961

(3) Outside camera

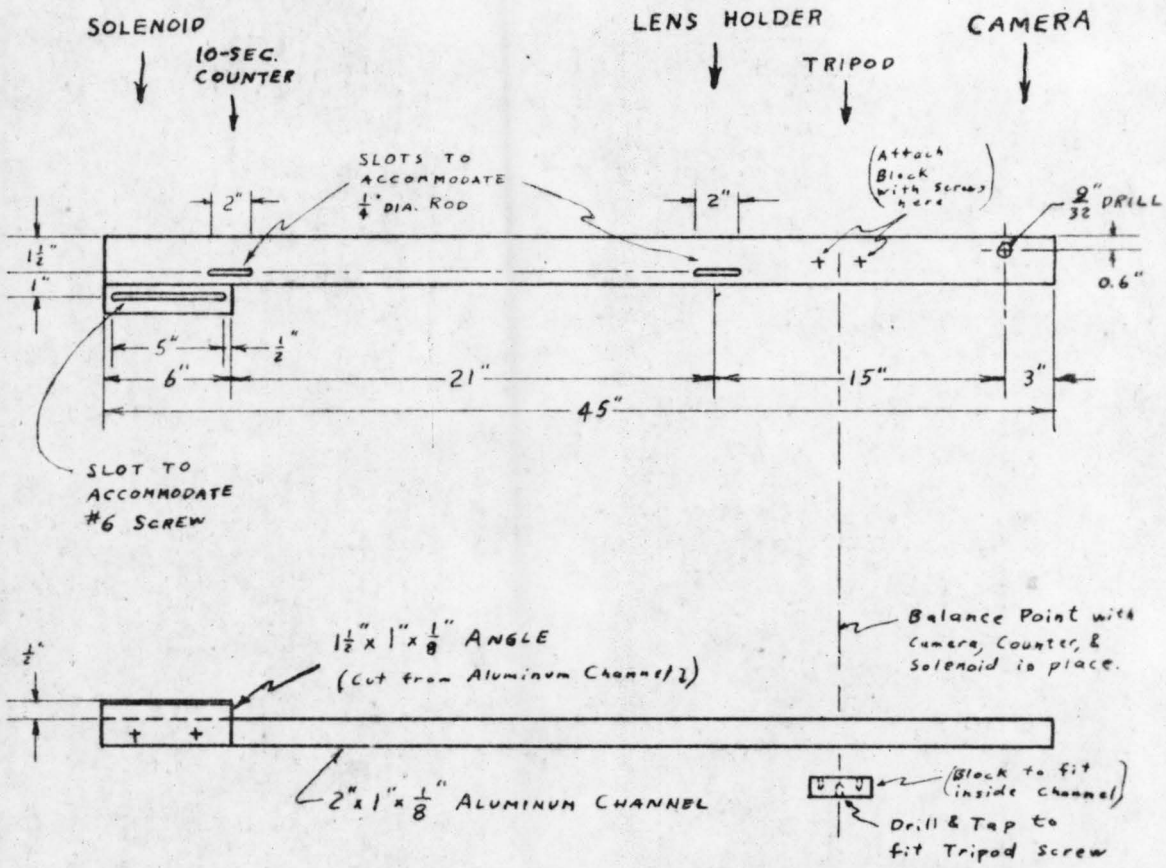
The outside camera is a Keystone (Criterion) 16 mm movie camera with a single-frame shutter release and a normally closed shutter. A Guardian 6 v. D.C. solenoid trips the shutter. This solenoid is wired in series with the power supply, the radar camera, and a microswitch which is triggered by the radar antenna once per revolution, thus exposing one frame approximately every five seconds. It is possible to operate the radar camera only by disconnecting the outside camera and inserting a "dummy" load (another solenoid) in its place. It is important to use this "dummy" to properly load the power supply. Kodachrome color film (film speed 10) was used in this camera. The lens opening should be determined with a light meter for best results, but f/8 may be used satisfactorily for most cases.

The outside camera was mounted on one end of an aluminum channel. The 10-second counter and solenoid were mounted on the other end, and a lens holder with a Series 5, + 2 Portra lens (close-up lens) was mounted between them and the camera lens shown in Figure 19. This entire unit was mounted on a tripod. To prevent the wind from overturning the tripod, an 18" piece of reinforcing steel with a loop at the upper end was driven into



LENS HOLDER

FOR SERIES 5, 2+ PORTRA LENS



OUTSIDE CAMERA MOUNT

FIG. 19

CSU PROJECT 2445 NOT TO SCALE DRAWN BY LB SEPT. 1961

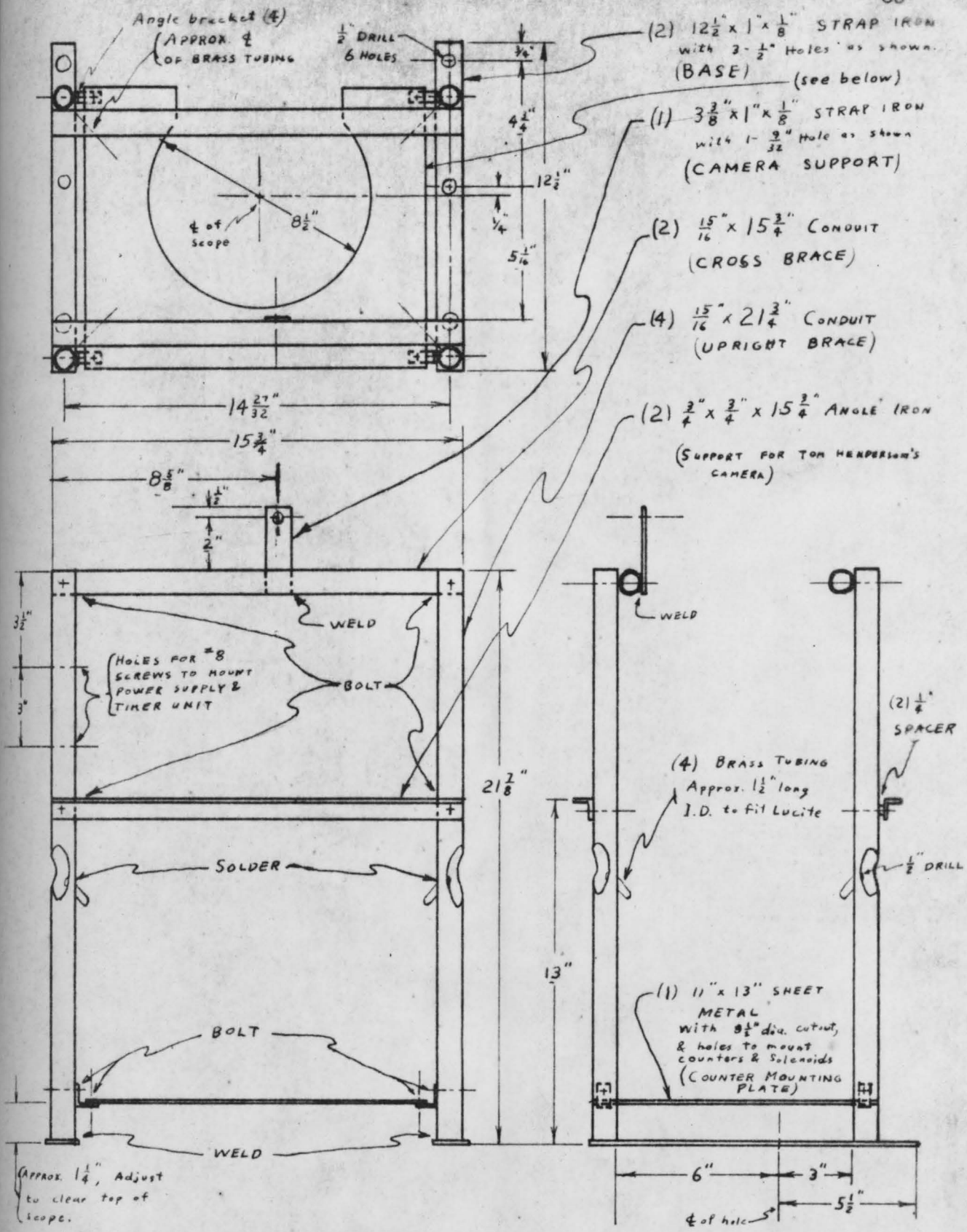
the ground directly below the tripod and the tripod is secured to it by means of a light chain and a turnbuckle. The present chain has "figure-8" links which tend to expand when the turnbuckle is tightened too much. Therefore, this chain should be replaced with a different type chain which would not stretch.

(4) Radar Camera

The "radar" camera devotes the camera used to photograph the radar scope. A Keystone "Criterion" 16 mm movie camera was modified to give a "normally open" shutter. The shutter was operated by a solenoid in the same manner as the outside camera. Tri-X negative film (film speed-320) was used with a lens opening of f/5.6.

The radar camera was mounted so that the front of the lens was 19 inches from the glass plate of the scope. The radar camera mount was constructed of 15"/16 conduit pipe and 1" x 1/8" strap iron. (Supports were provided for Tom Henderson's camera). (See Figures 19 and 20)

A sheet metal plate was attached to the face of the repeater scope approximately 1-1/4" above the face (so that it will clear the top of the scope). On this plate were mounted four 3-digit counters which recorded (1) the month and date in the upper -left hand corner, (2) the antenna elevation (in degrees), in the upper right-hand



RADAR CAMERA MOUNT

FIG. 20

(SEE NOTE 2)

CSU PROJECT 2445

BUILT JUNE 1961

SCALE: 3/16" = 1" (APPROX)

DRAWN BY LB, SEPT. 1961

corner, (3) lapsed time in minutes since 0800 MST in the lower left-hand corner, and (4) lapsed time in the 10-second units since 0800 MST in the lower right-hand corner. These counters were mounted in the corners of the camera's field of vision which was approximately 7-1/2" x 10-1/2" wide at 19 inches distance. The power supply and timer unit were also fastened to the camera mount. A 12 v. bulb (No. 67 W) to light the counters was mounted approximately half-way up each of the uprights of the frame. These bulbs were suspended from the top of the frame by their electrical wires. The uprights were partially cut away to permit access to the bulbs. The openings were covered by metal sleeves which fit around theuprights. This is done to prevent stray light from striking the radar scope. The light was "piped" to the counters by tubular pieces of lucite which had been bent so that they are aimed at the counter at approximately a 45° angle. It was necessary to avoid sharp bends, since sharp bends destroy the light "piping" qualities of the lucite. The end of the lucite "pipes" should be approximately 1/2" from the counter in order to avoid reflections which would be seen by the camera. (The present equipment does not meet these specifications and should be modified for better photos). The lucite "pipes" are held in place by

tubing (which makes a snug fit with the lucite) which is soldered to the upright over a hole which allows the light from the bulb to strike the upper end of the lucite.

The entire mount is covered by a black corduroy hood to shut out room light. The hood is 14" deep, 22" wide, and 36" high with a hole, covered by a flap, in the front for checking the interior equipment.

(5) Interconnection

The various components are connected (See Figure 18) by Whitaker "ends" soldered and crimped to the wires. These ends are then inserted into the proper connection.

(6) Dates and times of photography

The dates and times of operation of the time-lapse camera equipment for cloud photographs are shown in Table 10.

Details on dates and timer of radar scope photographs are given elsewhere.*

---

*Schleusener and Henderson: CER61RAS58, Table 1.

TABLE 10

CLOUD TIME-LAPSE PHOTOS TAKEN AT RADAR SITE-1961[3]

DATE	Time (MST) Begin	Time (MST) End	FEET	
13 June	1605	1630	10	Test
29 "	1535	1650	40	Test
7 July	1500	1800	55	
8 "	1420	1636	45	
28 "	1550	1900	50	
1 Aug.	1140	1625	70	

[3] For a record of time-lapse photos taken of the radar scope see Table 1 of the above report.

b. Hail genesis area analysis--topographic lift computations (by Loren Blandin).

Topographic lift is the lifting effect which results when a wind blows against a change in elevation of land. It is computed in terms of FEET (of increase in elevation.) PER HOUR. The purpose of the computations and analysis is to determine whether or not (topographic) lift is a significant factor in the formation of hailstorms. The purpose of this report is to explain the procedure used to compute and analyze lift. All data, except the plots of echo centroids, are in a separate notebook titled "Genesis Area Analysis."

Terms which may need definition are origin, genesis point, echo, track, area of interest, and lift difference. Echo refers to the radar echo (bright spot on the radar scope) of an area of a cloud which contains enough precipitation to be detected by radar. Origin refers to the location at which a radar echo first became strong enough to be detected. The genesis point is an arbitrary point assumed to be the location at which a cloud begans to form. [See section (3)]. A track is the approximate path of the centroid of an echo. Area of interest refers to the area within a 75-nautical-mile radius of the radar station. Lift difference is the lift at the genesis point minus the average lift of the four surrounding points.

The criteria for selecting the echoes for lift computations are as follows:

1. Origin occurred within area of interest.

2. Origin occurred within the first two hours after the detection of the first echo of the day.

3. Echo duration was at least 45 minutes.

4. Cell formation was not influenced by other cells.

There are five steps involved in lift computations, (1) plotting the centroids of echoes, (2) finding wind velocities, (3) finding elevations, (4) computing lift, and (5) analyzing the data.

(1) Plotting echo centroids

The centroids of the echoes are plotted on a 4' x 4' sheets of tracing paper to a scale of 1:250,000 (100 nautical miles equal 29.06 inches) with the aid of a polar coordinate grid underlay and using the following symbolic notation (See note (a), below).

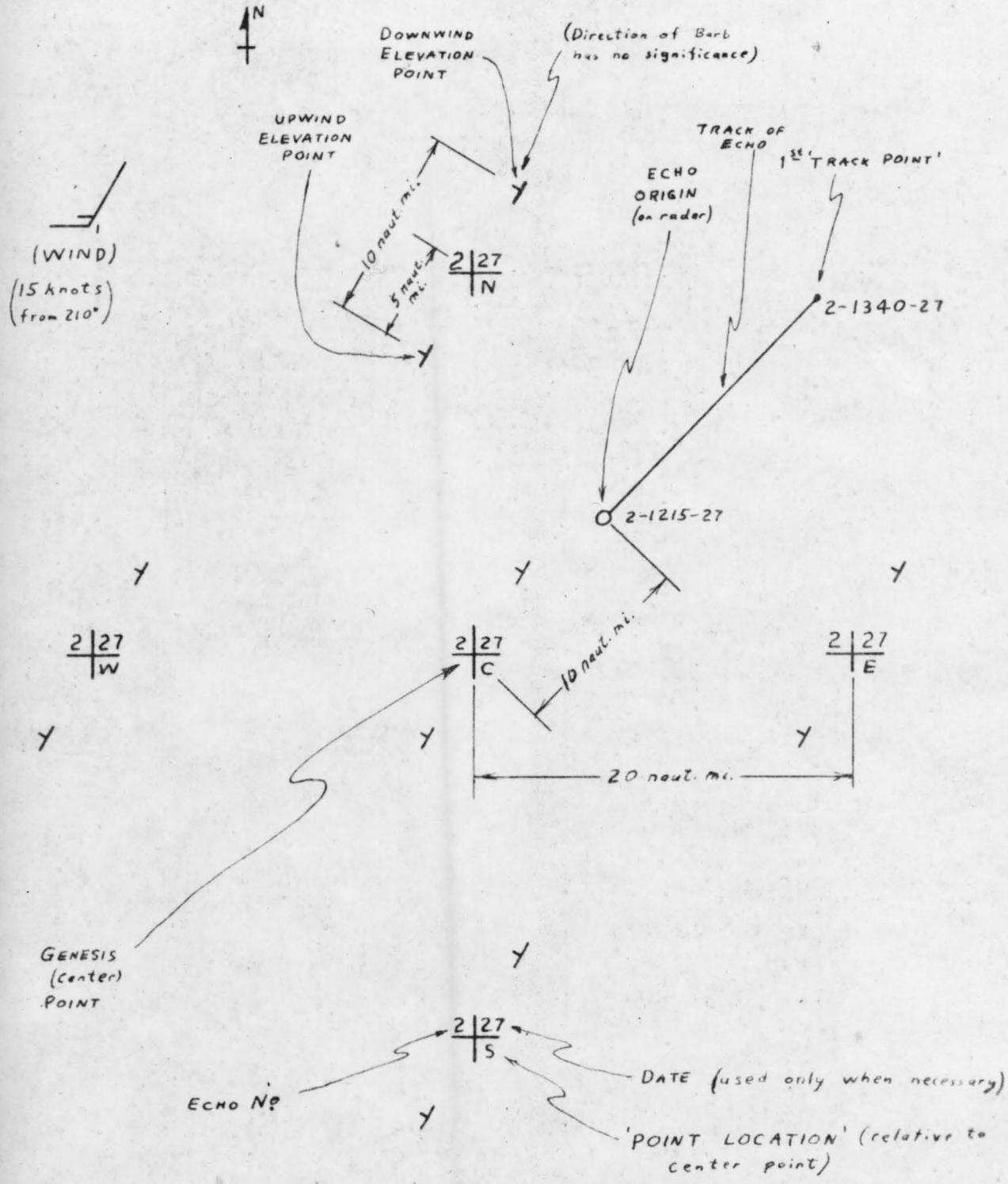
(a) A small circle designates the centroid of the origin of an echo. (See Figure 21)

(b) A dot designates the centroid of an echo at a point (as recorded by the radar observer) along its track--a track point. (See Figure 21).

(c) A straight line is used to connect the origin and successive track points of each echo, thus indicating its track.

(d) An arrowhead indicates the approximate location at which the echo dissipated.

(e) An arrowhead ending on the track of another echo indicates that the echo merged with the other echo.



LIFT COMPUTATIONS' ANALYSIS POINTS

FIG. 21

CSU PROJECT 2445 DRAWN BY LB SEPT. 1961

SCALE: $\frac{1}{8}$" = 1 NAUTICAL MILE

(f) A center line (————————) is used to indicate the approximate center line of a long echo.

(g) When an echo crossed the boundary of the area of interest, its track is simply begun or terminated at the boundary with no special notation.

(h) At each echo location recorded by the radar observer the echo number and the time are indicated by two number groups separated by a dash. When more than one day's echoes are plotted on a sheet, the day of each echo is indicated by a third number group. For example, 12-1420-26 means echo No. 12 at 2:20 pm on the 26th of the month. (See note (b) below.) For the lift computations only the genesis point and the first track point are required.

(2) Finding wind velocities

Since wind direction is used in finding the elevations and wind speed is used in computing lift, it is necessary to determine the wind velocity around the genesis point. This was done by plotting the 1800 Z 8,000 ft. winds for Denver (D), Goodland, (GLD), North Platte (LBF), Cheyenne (CYS), Scottsbluff (BFF, formerly SCT), and Sterling (STK). The Sterling wind data were obtained from pilot balloon observations. (See section II-C-1 of this report.)

The data for the other stations were obtained from teletype reports obtained through the U.S. Weather Bureau at Stapleton Field.) Flow lines were then drawn on the maps, and the wind velocities are estimated by interpolating between those lines. The same wind was used for the genesis point and the four surrounding points. (See below).

(5) Finding elevations

For the purposes of analysis the genesis point was assumed to be 10 nautical miles up-motion from the origin. For comparison, four surrounding points--one in each cardinal direction from the center (genesis) point--were selected on a 20 - nautical - mile radius from the center point. Elevations used in the computations were chosen 5 nautical miles on either side of point being analyzed on a line parallel to the wind direction. All of the above points are marked on the 4' x 4' sheets and labelled as shown in Figure 21. Each 4' x 4' sheet was then overlaid on a topographic map, and the elevations were read to the nearest 100 feet and recorded.

The topographic map consists of six standard topographic maps [See note (6)(c) below] having a scale of 1:250,000. Note that the contour interval is 200 ft. for the western three maps, and 100 ft. for the eastern three.

(4) Computing lift

The formula for lift is

$$\text{LIFT} = \frac{\Delta h}{d} \cdot v$$

where

Δh = downwind elevation minus upwind elevation (ft)

d = distance between elevations (10 nautical miles)

v = wind speed (knots = nautical miles per hour)

therefore: $\text{LIFT} = \frac{\text{ft}}{10 \text{ naut. mi.}} \times \frac{\text{naut. mi.}}{\text{hr.}} = \frac{\text{ft.}}{\text{hr.}}$

The average of the lift at the four surrounding points was calculated in order to compare directly with the lift at the genesis point. The former was subtracted from the latter to give a "lift difference," the sign of which was used to determine the significance of the data (See section (5) below.)

Following are explanations of the data sheets used in this computation.

Wind. The first column contains--in symbolic notation--the approximate wind velocity for 1800 z at 8,000 ft wind at the genesis point for each echo.[4]

Date, Echo No. In the second column the computations are listed chronologically by date and sequentially by echo number. The dateis written only on the first line of computations for that date; the echo number is written

on the first line of its group of five computations. Echoes which produced hail are indicated by writing the word Hail below the echo number. (See note (6)(e) below).

Echo time, point. In the third column the time of origin of the echo is recorded under echo time. Under point the "point location"--N, E, S, W, and C (See note f) is recorded. (See Figure 21).

Elevations. For each point the downwind and upwind elevations are recorded in columns 4 and 5, respectively.

Δh is the change in elevation from upwind to downwind. (See Section 4).

Lift of surrounding points. The individual lift values for the four surrounding points only was recorded in column 7.

Σ Lift--The sum of the values in column 7 for each echo is written in column 8.

LIFT--The average of the lift values at the four surrounding points, is recorded in the ninth column. The lift value at the genesis point was recorded in the tenth column.

Lift difference--Column 11 contains the sign of the lift difference (genesis point lift minus the average lift of the four surrounding points). See note (6)(g) below.

For example, for an extreme case, one point might have been on a peak while the other was in a valley, thus giving a very large value for Δh, but the actual slope trend may have been in the opposite direction.

Also in 1961, three types of a "roughness index" were investigated. The first was simply a count of the number of contour lines crossed by a straight line between the two elevation points, (taking into account the two different contour intervals) for each pair of elevations. The second found by computing the standard deviation of the five downwind elevations (any five consistent elevations) could have been used, for each echo. The third roughness index was found by computing the standard deviation of the five Δh's for each echo. All three indices were discarded.

SUMMARY OF DATA 1961

Category	Lift Averages: Genesis Points	Lift Averages: 4 Surrounding Points	Difference	No. of Cases +	No. of Cases -	X^2	Prob.
I Hail	+2985	- 938	+3923	14	13	.037	.80 to .90
Non-Hail	-14585	-13,080	-1505	36	31	.373	.50 to .70
II Hail	+1415	+ 426	+ 989	10	10	.000	.99
Non-Hail	- 300	- 1,903	+1603	25	19	.82	.30 to .50
III Hail	+ 20	- 310	+ 330	3	2	.20	.10 to .20
Non-Hail	+ 550	- 768	+1318	8	1	5.44	0.02

Only category III Non-Hail cases were significant. At the 5 per cent level.

(6) Special Notes

(a) In some cases in 1961, the outline of a very large echo was indicated by dashes. Since this is unnecessary and tends to be confusing, it should be discontinued.

(b) The date(s) of all echoes on a sheet are written in in the lower right corner of the sheet with the level (surface, in all cases), the date plotted, and the plotter's initials.

(c) The topographic maps used are as follows: NK 13-8 (Cheyenne), NK 13-11 (Greeley), NJ 13-2 (Denver), NK 13-9 (Scottsbluff), NK 13-12 (Sterling), and NJ 13-3 (Limon). They are for sale by the U.S. Geological Survey, Denver 2, Colorado.

(d) The symbolic rotation indicates the wind speed to the nearest 5 knots. In 1961, by error the speed was converted to (statute) miles per hour for the lift computation so the units of these computations are actually ft.-stat. mi./naut. mi.-hr., and are therefore high by a factor of 1.15. In the report prepared from the 1961 data only the difference of two values was used so the above error had no effect. However, any time the actual values are used this error should be taken into account.

(e) In some cases in 1961, the duration time of the echo was also recorded in column 2.

The 1961 lift computations were made before the fourth criterion was imposed. The echoes which met this criterion are indicated by a blue check after the echo number. The lift valves for theses echoes were then copied onto separate sheets, which are in the summary section of the "Genesis Area Analysis" notebook.

(f) By always recording the points in the same order--North, East, South, West, Center (genesis)--a pattern is set and errors are reduced.

(g) See section 5 for explanation of astericks.

In 1961, the valve of lift difference was recorded but only the sign is necessary.

(h) The cases to be omitted for category 2 were indicated by a red asterisk.

(i) Category 3 also omits the cases omitted for category 2; Additional cases to be omitted were indicated by a blue asterisk.

5. Photographic Data Collection

a. Stereo Cameras

(1) Objectives

The purpose of stereo cameras as used during the summer of 1961, was to determine from groundlocations the spacial positions of identifiable points on clouds, the

primary interest being in the development of hail clouds. The units were capable of locating a point with an accuracy of 1/500 providing that the distance of the cloud from the camera was not more than 20 times the baseline.

(2) Equipment

The cameras used were type K-24 aerial cameras taking 5" x 5" pictures mounted similarly to a transition 20 second transit plates. A transit scope was fastened to the camera in such a mount that the optical axis of the transit was parallel to the optical axis of the camera. The unit was operated in the same manner similar to a transit. The construction of the camera mounting allows the horizontal direction of the camera to be set to 15 seconds, and the vertical direction to be set to 20 seconds.

The camera could be fired either manually or electrically with a 24 VDC source of power. The horizontal stability of the camera with respect to changes of azimuth while firing was found to be greater when fired electrically than when fired manually. Accuracy of the vertical setting was increased to 10 seconds by adjusting the camera to a horizontal position by means of a surveyor's level bubble. This leveling restriction limited the cameras field of view to a 20° vertical span immediately above the horizon. However, virtually all of the clouds of interest did not exceed this height.

For ease of reduction, the glass plate which held the film in place was etched with cross hairs which were then reproduced on each photograph.

An information board with a condensing lens was placed in front of the camera so that pertinent data such as time of exposure, date, direction of picture, and photo number could be recorded on the film. The arrangement of the location of the condensing lens is shown in Figure 22.

(3) Field Operation

(a) Field geometry and orientation

Three points were established Northeast of Fort Collins which formed a triangle whose three sides served as baselines. The cameras were set up on two of the three points. The baseline connecting those points was assumed to be a true North-South line so far as the horizontal orientation of the cameras in the field was concerned. The Northernmost camera was set so that the azimuth scale read 180° when sighting on the Southernmost camera stations. In the same manner, the Southernmost camera was set such that the azimuth index read 0° when sighting on the Northernmost camera station. This procedure set the lower plates of both cameras in the same position. Thus with the same horizontal setting on both cameras, the lines of sight of the cameras would be parallel, as shown on Figures 23 and 24.

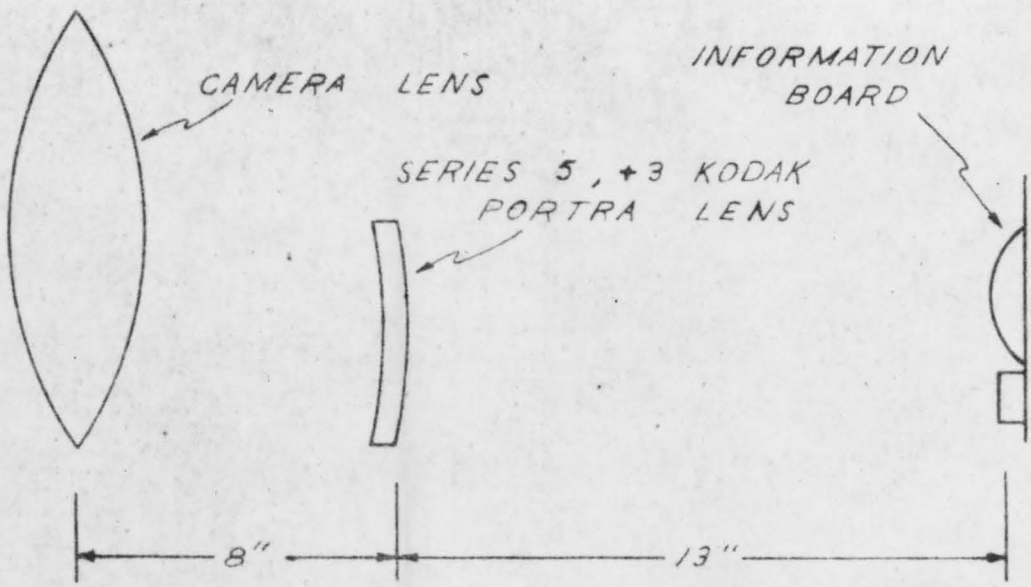


FIG. 22- STEREO CAMERA CONDENSING SYSTEM

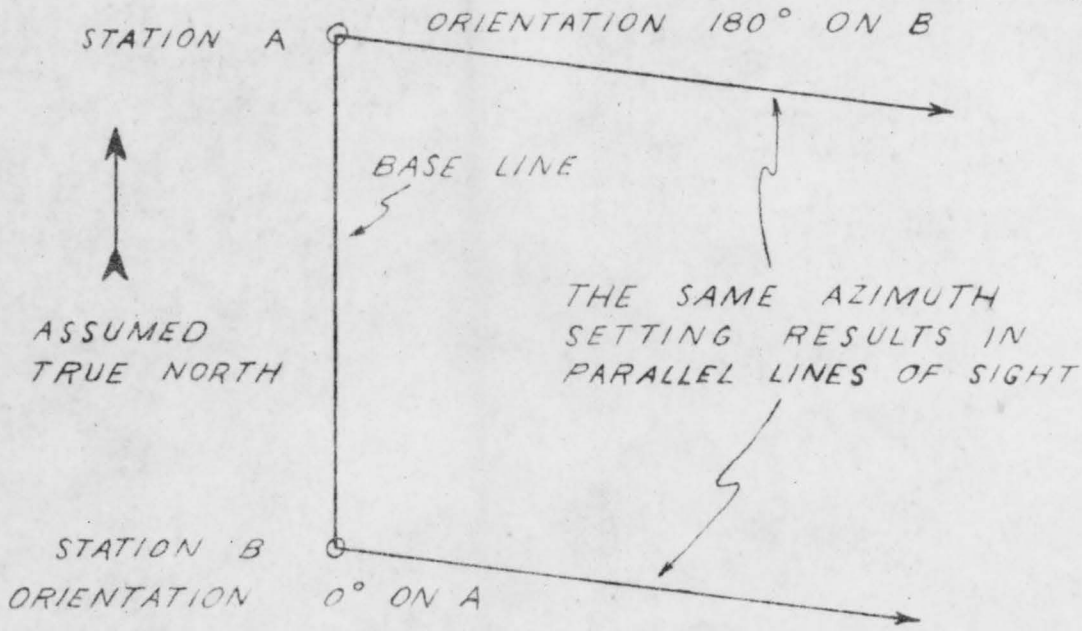
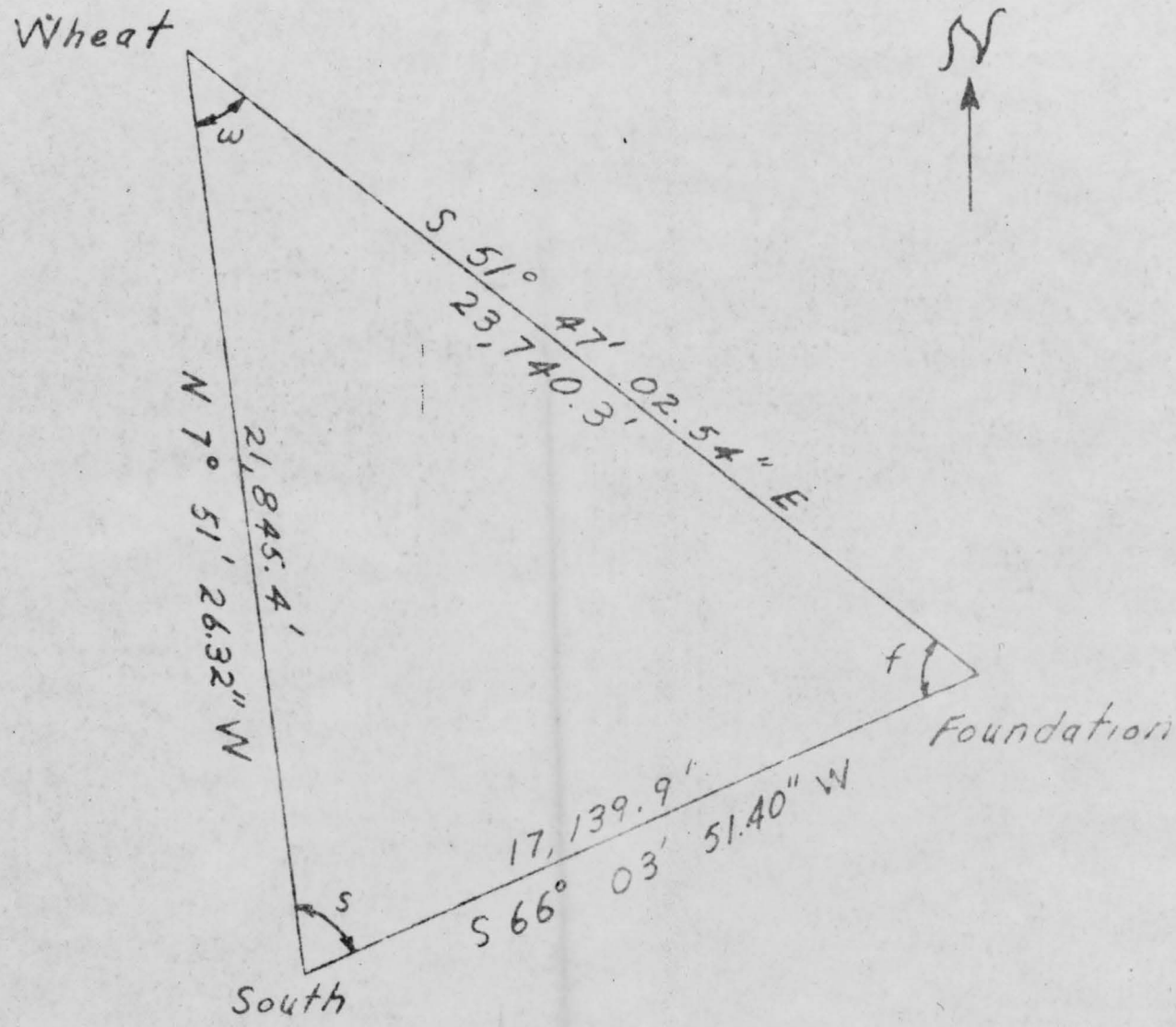


FIG. 23-STEREO CAMERA FIELD ORIENTATION

Fig 2 Stereophotography

Field Network



Station	Wheat	South	Foundation
Int. Angle	43° 55' 36.22"	73° 55' 17.72"	62° 09' 06.06"
X Coordinate	2,156,422.4	2,159,408.8	2,175,074.8
Y Coordinate	491,471.7	469,831.4	476,785.3
Elevation	5461		5302.5

(b) Methods of photography

Photographs were taken from both cameras simultaneously with cameras aimed at the same cloud. Class D radio transceivers were used for communication and to give command signals for firing. Picture frequency was determined principally by observation of the cloud rate of growth. During relatively stable periods, 5 minute intervals between pictures was used. During active cumulus growth, 1 minute or 30 second intervals were used.

All of the photograph pairs taken were taken with the optical axes of the cameras parallel. A stronger analytical solution would have resulted had each camera been sighted directly on the cloud of interest. However, for the mechanical solutions described in the section on computation, it was required that the axes be parallel.

(c) Field checks

Certain checks were made in the field to minimize errors. Since the azimuth plate was set by sighting the other camera satation with the transit scope, the accuracy of the azimuth setting was determined by how nearly parallel the optical axis of the transit was to the optical axis of the camera. To be sure that the two axes had not changed from their adjusted parallel position, a test photo was taken at the beginning of each days shooting.

A distant, well defined point was centered on the transit cross hairs and a photograph taken. If the cross hairs of the camera plate, as reproduced on the photograph, were centered on the point, then the scope axis and camera axis were considered to be essentially parallel.

A second precaution that was taken was to check the orientation of the azimuth plate from time to time during a days shooting particularly when magazines were changed. This assured against errors due to slight movement of the plate due to wind vibration or physical handling of the camera unit.

(4) Reduction of data

Two types of reduction will be used in the analysis of the results. One type is an analytical reduction of the spacial position of individual points; identifiable on both of a photographic pair. The other type will be a mechanical solution producing directly to scale a profile and plan view of a cloud or cloud system.

(a) Analytical reduction--By knowing the orientation of both photographs at the time the pictures were taken and the location of any point under consideration on both photographs, the spacial location of the point may be computed. A Haagstreit coordinatograph was used to locate points on the negatives. The distance of the points from the two axes was determined with an accuracy of .02 mm.

Due to the time involved in computing the point locations a computer program was set up in the Intercom Interpretive Double Precision Routine code for use on either the Bendix 6-15 or IBM 1620 machine. With the program, data were entered manually. The program has since been rewritten in the Fortran for use with all IBM machines, and with the new program, data entry is accomplished through cards or tape.

(b) Error analysis

The experimentally determined probable error of a point location was 1/800.

(c) Mechanical reduction

This method was designed as a rapid continuous reduction of the cloud outline to scale both in plan and profile. The accuracy of the point location by this method is approximately 1/200. One restriction of the mechanical reduction is that the camera axes must have been parallel when the pictures were taken. This restriction does not apply to the analytical reduction.

(5) Data obtained

Table 12 summarizes the data obtained from the stereo cameras during the summer of 1961.

TABLE 12. DATA FROM STEREO CAMERA

May 11 -- 50 pairs, 1605 - 1712, South - Foundation
sighting northwest.

May 16 -- 16 pairs, 1226 - 1247, wheat - South,
sighting northeast.

May 24 -- 37 pairs, 1216 - 1308, wheat - South,
sighting Southeast.

May 30 -- 30 pairs, 1135 - 1422, wheat - South,
sighting West and East.

May 31 -- 33 pairs, 1115 - 1410, wheat - South,
sighting West.

-- 77 pairs, 1512 - 1724, Foundation - South,
sighting Southeast and West

June 14 -- 33 pairs, 1100 - 1236, wheat - Foundation,
sighting West and East

June 19 -- 7 pairs, 1744 - 1759, wheat - South,
sighting East.

June 26 -- 130 pairs; 1235 - 1643, wheat - South,
sighting West and East.

July 7 -- 43 pairs, 1706 - 1829, wheat - South,
sighting East.

July 14 -- 57 pairs, 1543 - 1553, wheat - South,
sighting East

July 27 -- 10 pairs, 1543 - 1563, wheat - South,
sighting East.

Aug. 1 -- 100 pairs, 1149 - 1526, wheat - South,
sighting NE to SE.

b. 16 mm time-lapse photography

(1) Objective

The 16 mm time-lapse photography was used to record the development of cloud cells and portions of cells over an extended length of time through the use of a movie camera taking one frame every few seconds.

(2) Equipment

The camera used was a Keystone 16 mm camera equipped with a solenoid for electrical firing of one frame at a time and apparatus for automatic electric winding. A Meteorological Research Inc. timing mechanism automatically fired the camera one frame at a time on a preset, adjustable time interval.

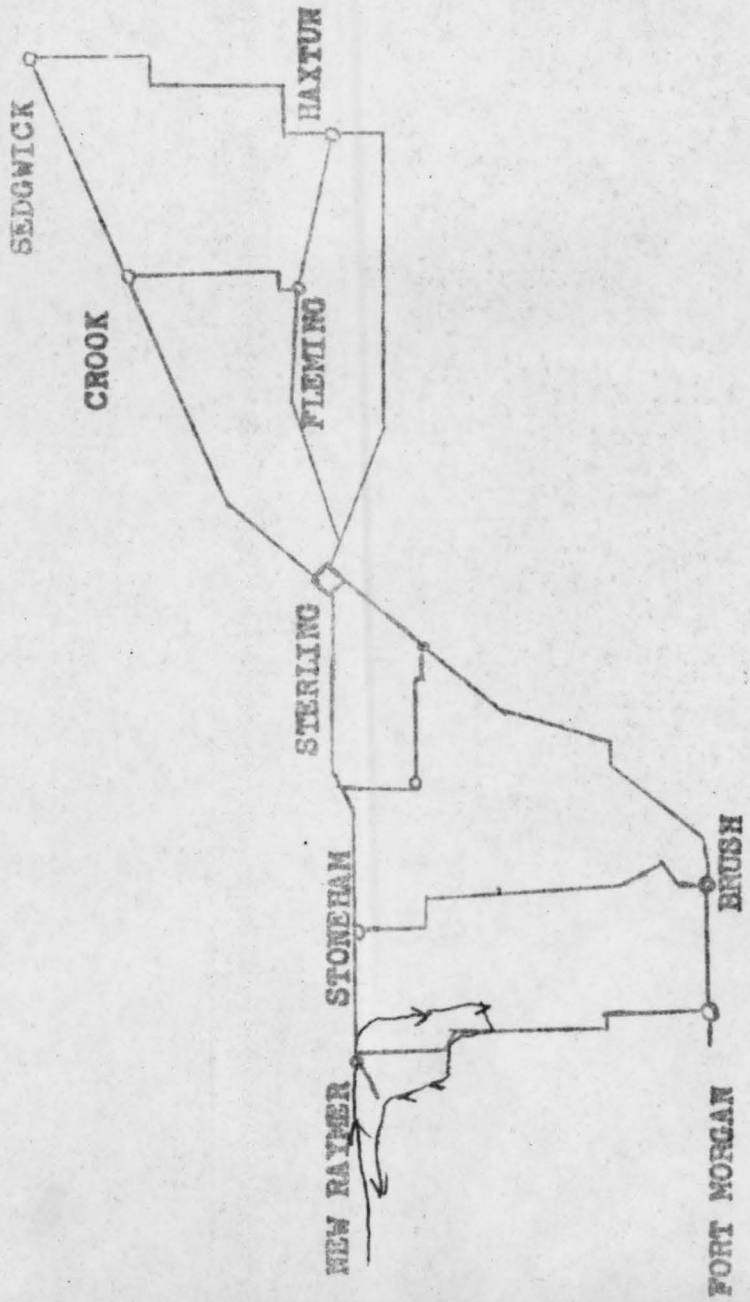
A lens condensing system was set in front of the camera to record the time of each frame. Both the camera and condensing system were mounted on a two-inch aluminum channel supported by a tripod. Figure 25 shows the location of the condensing lenses and clock for each of the three lenses used on the camera. The lenses and camera are attached to a two-inch aluminum channel which was slotted to accommodate the lens holder and clock board. The channel is supported by a standard camera tripod. The condensing lenses used were series 5, +1 and +2 Kodak portra lenses.

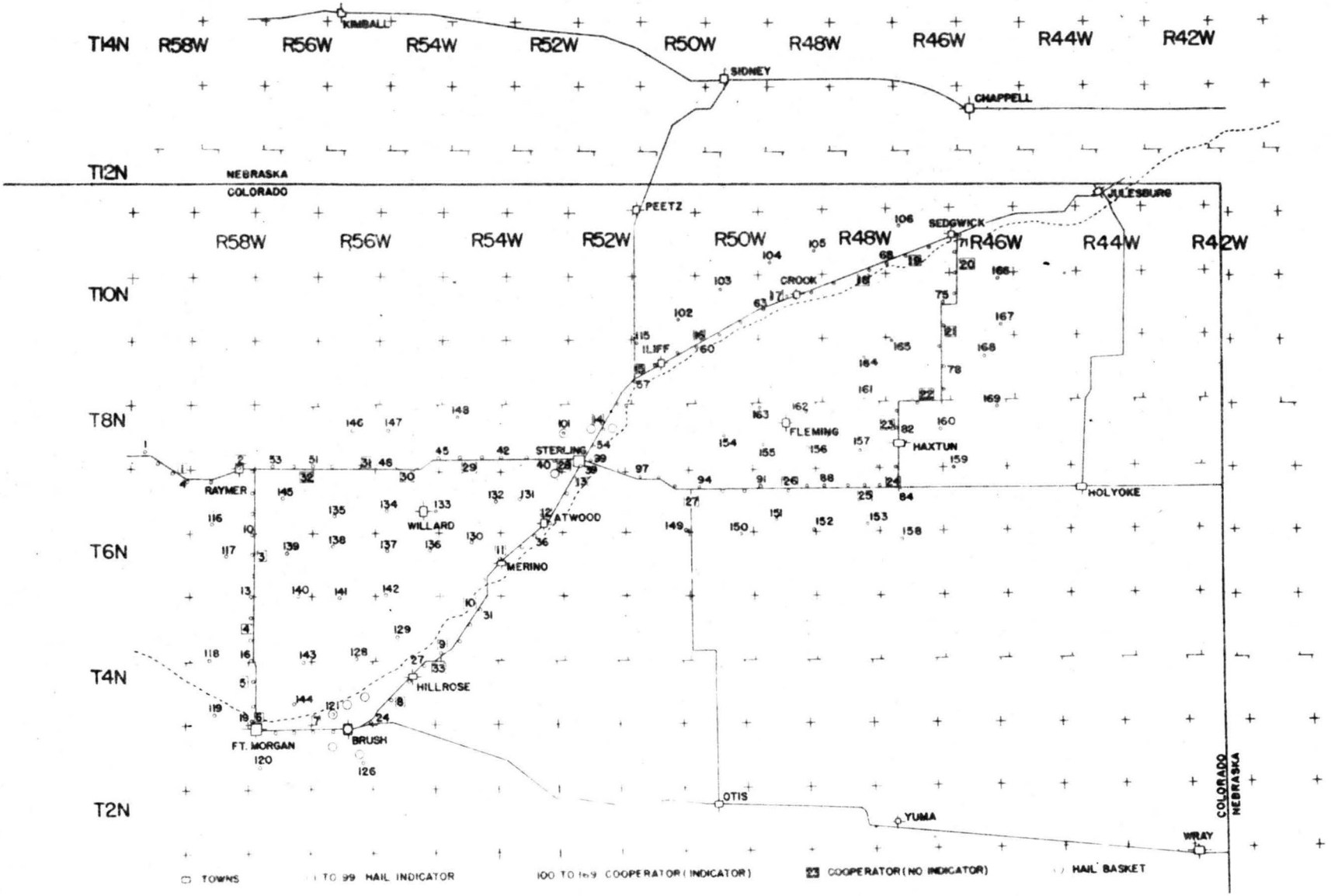
FIELD TRIP ROUTE - CSU PROJECT 2445

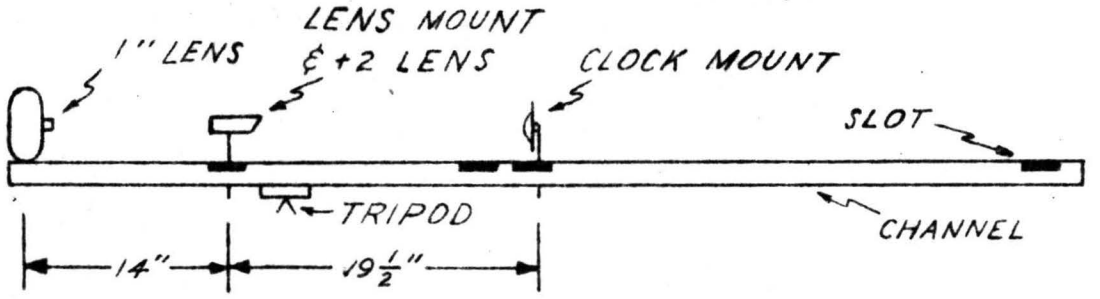
Name(s) Lewis O Grant Date(s) of storm

Vehicle 2741 Date of ~~inspection~~ Establishment 1 May 1962

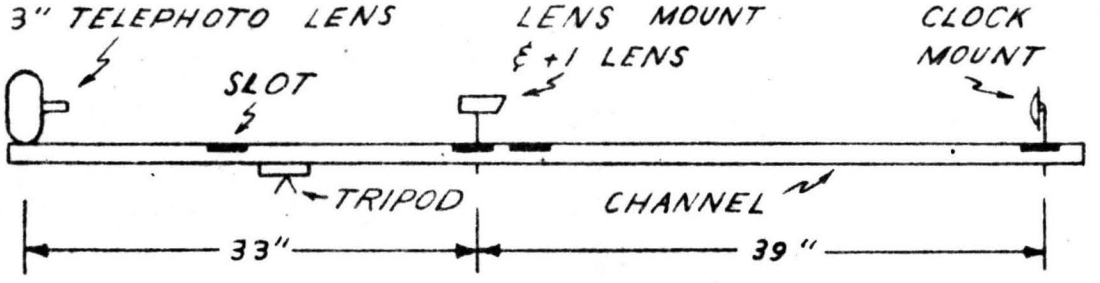
(Continue notes on reverse side if necessary.)



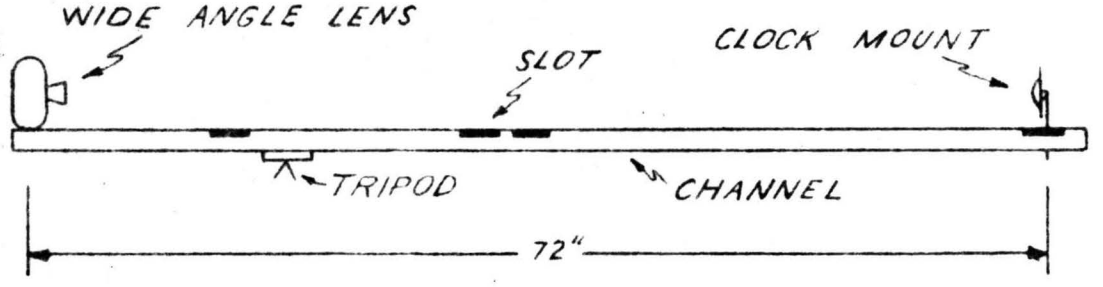

T14N
R58W
R56W
R54W
R52W
R50W
R48W
R46W
R44W
R42W
KIMBALL
SIDNEY
CHAPPELL
T12N
NEBRASKA
COLORADO
PEETZ
JULESBURG
SEDGWICK
T10N
CROOK
ILIFF
T8N
STERLING
FLEMING
HAXTUN
RAYMER
HOLYOKE
WILLARD
ATWOOD
T6N
MERINO
T4N
HILLROSE
FT. MORGAN
BRUSH
T2N
OTIS
YUMA
WRAY
COLORADO
NEBRASKA
TOWNS
1 TO 99 HAIL INDICATOR
100 TO 199 COOPERATOR (INDICATOR)
COOPERATOR (NO INDICATOR)
HAIL BASKET



16 mm. CAMERA WITH 1" LENS



16 mm. CAMERA WITH 3" LENS



16 mm. CAMERA WITH WIDE ANGLE LENS

FIG. 25 - LENS CONDENSING SYSTEM
16 mm. TIME LAPSE CAMERA

(3) Field Operation

The time-lapse movies were usually taken at the stereo camera stations while the cameras were in operation. Very often, the same cloud or system was the object of both stereo and time-lapse cameras. On some days when the stereo cameras were not in operation, the time-lapse unit was operated from the roof of the Engineering Building.

(4) Data obtained

Table 13 gives a summary of the data obtained from the 16 mm camera during the summer of 1961. (Note: see also section II - C - 2 -(a) - (6), Table 10, for additional times of 16 mm time-lapse photography taken from radar site at New Raymer.)

4. Airplane Flights (In separate report)

5. Facsimile Data

Table 14 gives a list of fax maps available for use during the period from the 15th of May through the 15 of August 1961.

LE 13. DATES AND TIMES OF TIME-LAPSE PHOTOGRAPHY

te	Location	Time	Lens	Ft.	Direction
1-61	South	1510-1530	Reg	5	N
		1530	W A		Pan
		1535-1621	Reg	15	NNE
		1623-1722	W A	19	N
		1730	W A	4	Pan
6-61	South	0912-	Reg	11	250°
		1135	Reg		Pan
		1138-	Reg	6	250°
		1148-	Reg	4	250°
		1515-	Reg	20	160°
4-61	South	1133-1212	Reg	13	70°
		1212-1500	Reg	53	90°
		1525-1548	Reg	7	160°
0-61	South	1041-1508	Tel	79	240°
1-61	South	1022-1141	Tel	18	275°
		1209-1233	Tel	9	250°
		1233-1312	Tel	5	225°
		1312-1400	Tel	7	215°
		1400-1733	Tel	68	330°
4-61	South	1204-1341	Reg	31	110°
		1353-1535	Tel	33	310°

Date	Location	Time	Lens	Ft.	Direction
6-19-61	South	1246-1310	Tel	9	90°
		1331-1429	Reg	17	90°
6-21-61	South	1615-	Reg	22	Pan 270-150
		1620	Tel	7	90°
		1655-	Reg	2	70°
		1720-1757	Reg	9	90°
6-26-61	South	1122-1526	Tel	36	80°
		1526-1628	Tel	8	110°
		1628-1705	Tel	10	120°
7-7-61	South	1612-1722	Tel	25	120°
		1722-1810	Tel	15	45°
		1810-1843	Tel	11	140°
7-14-61	South	1452-1516	Tel	8	60°
		1516-1546	Tel	9	80°
		1548-1638	Tel	6	90°
8-1-61	D wing	0804-0821	Reg	5	30°
		0827-1038	10mm	38	40° & 80°
		1040-1138	10mm	18	60°
		1140-1321	10mm	30	20°
8-2-61	D wing	0923-1324	Reg	71	225°
		1324-1458	Reg	29	160°

TABLE 14, FAX MAPS AVAILABLE

Map #	DESCRIPTION
2	5 day forecasts, Tue., Wed, Fri.
	30 day outlook, 1st and 15th.
3	Radar summary (oz)
4	Weather depiction (oz)
9	Max. Temp. 12 hrs. (oz)
18	Stability and precipitable water
19	Radar summary (o3z)
20	Weather depiction (o3z)
21	850 mb. analysis (oz)
22	SFc. analysis (o3z)
23	700 mb. analysis (oz)
24	SFc. analysis (oz)
25	500 mb. analysis (oz)
25A	24 hr. 500 mb. and Vect. Prog.
26	Max. wind analysis (oz)
27	300 mb. analysis (oz)
28	200 mb. analysis (oz)
35	Radar summary (o6z)
38	SFc. analysis (o6z)
39	300 mb. analysis (oz)
45	Wind aloft-lower level (o6z)
46	Wind aloft-intermediate level (o6z)
51	Radar summary (o9z)
52	Weather depiction (o9z)
54	SFc. analysis (o9z)
57	500 mb. Vorticity (V.T. 12z)
58	SFc. analysis (ooz)
59	MKL Severe weather outlook
66	Radar summary (12z)
67	Weather depiction (12z)
69	SFc. analysis (12z)
72	Min. temps (12z)
73	Snow cover, 24 hr. rainfall (12z)
74	500 mb. radat. (12z)
75	12 hr. SFc. Prog. (V.T. 06z)
81	Stability and precip water (12z)
82	Radar summary (15z)
83	Weather depiction (15z)
85	Radar summary
86	700 mb. analysis (12z)
87	SFc. analysis (12z)
88	500 mb. analysis (12z)

TABLE 14, FAX MAPS AVAILABLE - continued

Map #	DESCRIPTION
88A	24 hr. 500 mb. and Voct. prog.
89	300 mb. analysis (12z)
90	200 mb. analysis (12z)
91	Max. wind (12z)
95	Radar summary (18z)
96	Weather depiction (18z)
98	SFc. analysis (18z)
99	300 mb. analysis (12z)
105	Winds aloft-lower (18z)
106	Winds aloft-intermediate (18z)
111	Radar summary (21z)
112	Weather depiction (21z)
114	SFc. analysis (21z)
117	500 mb. vorticity (0z)

III. ANALYSES

A. Outline of Analyses completed (by Earl Mason)

Following is an outline of the type of analyses completed by Earl Mason.

1960

DAILY HAIL AND PRECIPITATION PATTERNS

Plotted maps of precipitation amounts

Analyzed overlay of precipitation, isohyets of .1 inch, .25 inches and increments of .25 inch.

Overlay of cooperative hail reports plotted, showing relative time of occurrence in 15 minute intervals numbered from time of the first report, maximum and most common stone sizes using the code from the mailed in reports, and computed energy numbers, along with energy numbers computed from the observed size distributions from the indicators.

EXTENT OF CLOUD COVER FROM PHOTOS - JUNE 29, 1960

Map of leading edge of cloud cover

HAIL SEASON SUMMARY

A bar chart giving, by days, hail days in the area, hail days at Sterling airport, daily precipitation at Sterling, hail days at Denver, daily precipitation at Denver, hail days in the UAL network and thunderstorm days at Sterling airport.

SUGAR BEET DAMAGE ANALYSIS

Graphs of accumulative relative frequency of damage vs hail damage in percent of acres planted for districts in NE Colorado from 1928-1959.

TARGET-CONTROL ANALYSIS OF PRECIPITATION

A comparison of Gamma distribution transformed 1951-1958 and 1960 precipitation amounts with the base period prior to 1951 used in 1959.

COMPARISON OF HAIL DAYS BY QUADRANTS

A bar chart of hail days by quadrant through Sterling for 1959-1960.

MAPS OF MONTHLY PRECIPITATION AND PERCENT OF USWB NORMAL PRECIPITATION FOR 1960

ANALYSIS OF NETWORK

An analysis of reports received from the network to determine in a general sense the effectiveness of the return of reports, by months.

HAIL PATHS BY MONTHS

Maps of the general direction of movement of hail storms by months, determined from the times of reports.

CHARTS OF CHARACTERISTICS OF HAIL FALL

Maximum and most common hail size distribution by months
Time of hail onset, by months
Hail duration time
Percent of ground covered

ACCUMULATIVE RELATIVE FREQUENCY OF ENERGY NUMBERS FROM MAILED-IN REPORTS

HAYDEN HODGES SYNOPTIC TYPES FOR 1960 HAIL DAYS

MAXIMUM HAIL SIZE VS DENVER MAXIMUM WIND ALOFT

Accumulative relative frequency of maximum wind aloft for hail and no hail days.
Maximum wind vs maximum hail size reported.

CCL TEMPERATURE VS POSITIVE AREA, DENVER

Positive area defined as the product of the temperature differences from the CCL and the point through the elevation of -10C and the moist adiabat through the CCL, and -10C and the point at CCL level from the dry adiabat from -10C

ZONAL WIND ANALYSIS

Zonal winds, 25° through 75° for 1959, 1960, and 1961, with hail days and precipitation at Leadville and Sterling.
Comparisons to monthly means and USWB normals for NE Colorado and Alberta.

HAIL CASES - JUNE 20, 29, JULY 3, 1960

Surface Charts
Skew-T's
Wind Max charts
Trough position charts
Wind profiles at the tropopause chart
Stability index (USWB) chart

Precipitable water charts computed from assumed straight line sounding from the mandatory level data.
Low level maximum wind chart
Surface pattern charts
500 mb charts of troughs
55° dewpoint line chart
Height above ground of 0° wet bulb
Turning components along and at right angles to the mean wind.

1961

DAILY HAIL AND PRECIPITATION PATTERNS

Plotted maps of precipitation amounts
Overlay with cooperative hail reports plotted, showing relative time of occurrence, and maximum and most common hail sizes using the code on the mailed-in reports.

CHARTS OF CHARACTERISTICS OF HAIL FALL

Maximum and most common hail size distribution by months
Time of hail onset by months
Hail duration time
Percent of ground covered

B. Papers, Reports and Publications

The following reports, papers and publications are in the process of preparation from the data obtained during 1960 and 1961.

1. On the relation of the latitude and strength of the zonal westerlies to the occurrence of hail in the lee of the Rocky Mountains.
2. Case history studies 1960.
3. A report by Schleusener and Grant on the characteristics of hail storms in the Colorado State University network, prepared for the Kansas City Weather Radar Conference in October 1961.
4. The report "Hail Genesis Areas in and near Northeastern Colorado" by Schleusener and Henderson, prepared for the Crop Hail Actuarial Association.
5. On the position of hail fall with respect to thunderstorm precipitation, a paper being prepared for the Severe Storms Conference in Norman, Oklahoma in February 1962.