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FINAL REPORT

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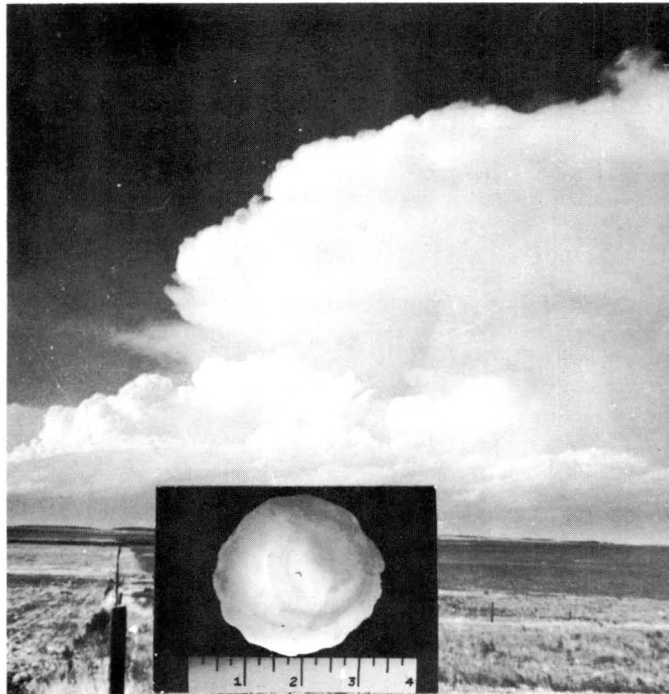
on

Research Conducted Under Grant NSF G12139

"CHARACTERISTICS AND FORMATION OF HAIL"

by

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ENGINEERING RESEARCH

SEP 19'73

FOOTHILLS READING ROOM

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The photo on the cover of this report was taken on 29 June 1960 from near New Raymer, Colorado, and shows the rear edge of a thunderstorm which was producing large hailstones at the time of the photo near Kimball, Nebraska. The insert shows a sample of the hailstones which fell in Kimball, Nebraska at about the time of the photograph of the thunderstorm. (Dimensions of the scale are in inches.)

CONTENTS

	<u>Page</u>
INTRODUCTION	5
SUMMARY OF SIGNIFICANT RESULTS	5
Instrumentation	5
Observations of Hail	5
REFERENCES	8
ILLUSTRATIONS	9 & 10

FIGURES

<u>Figure</u>	<u>Page</u>
1 Cumulative frequency (percent) of hail impact energy values (ft-lb per sq ft). E_{max} values are computed on the assumption that all stones are of the largest size; E values are computed from observed size distributions	7

TABLES

<u>Table</u>	<u>Page</u>
1 Volume of ice (cm ³ /cm ²) and estimated impact energy (ft-lb/ft ²) by hail size class for 1960-1961. Data from hail indicators were obtained from the Colorado State University hail network	6
2 Comparison of total volume of hail and total impact energy from hail with area of sugar beets damaged from hail, 1960-1961	6



CHARACTERISTICS AND FORMATION OF HAIL

INTRODUCTION

Colorado State University became involved in studies of hail for the first time in the summer of 1959. At that 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. Analysis of the field data which were collected in connection with the evaluation study was supported by the National Science Foundation. The results of the evaluation, reported in the final report of research conducted under Grant NSF G10036, embodied the idea of "cautious optimism", resulting from an apparent reduction in hail impact energy associated with the seeding. Moreover, a target-control analysis of precipitation indicated a positive precipitation anomaly for the area included in the cloud seeding program.

Since the results of the evaluation study (based on limited observations made during an operational program, and not a designed experiment) were not conclusive, a more basic study of the characteristics and formation of hail was begun in 1960. The successive objectives of the studies which began in 1960 consisted of the following:

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

The primary purpose of work conducted under Grant NSF G12139 was for the attainment of the first two of these four objectives. Later work was directed toward the accomplishment of the third and fourth objectives.

SUMMARY OF SIGNIFICANT RESULTS

Instrumentation

Data on hail and precipitation were collected from the Colorado State University hail network from 15 May - 15 September 1960 and from 1 May - 15 August 1961. In addition to data obtained from volunteer observers [1]*, data were obtained from hail indicators [2] and timing devices designed to give the time of first hailfall.

Hailstones were collected for analysis from cooperative observers and also from mechanically cooled hail collection chambers. Techniques were developed for slicing the stones with electrically heated wires, and for obtaining thin sections for air bubble and crystal analysis.

Efforts to develop additional low-cost instrumentation for the hail network were not successful. A prototype model was built for a size-sorting device for hail that would provide beginning and ending times of rain and hail, using photographic recording. A similar prototype model was built of a system for recording (photographically) hailfall and concurrent temperature and wind. However, the costs for these items of equipment were too high to be economical for the hail network, so no additional units, other than the prototypes, were built.

Observations of Hail

Results of the study are presented in detail in papers prepared by the author and others, [A, B, C, D, E]. Significant findings include the following:

*Numbers and letters in brackets refer to appended references.

- Information is available on the frequency, duration, diurnal variation, and intensity of hail. [C]
- The total quantity of ice that falls as hail, as well as the estimated impact energy per unit area from hail, appear to be closely related to crop damage, as shown in tables 1 and 2, extracted from [A]. These results

indicate that the data obtained from the hail network (energy values, or estimates of depth of ice) are probably quite representative of hail damage to crops; further, that data of this type obtained from the network could serve as the basis for evaluation of hail modification experiments.

TABLE 1

Volume of ice (cm^3/cm^2) and estimated impact energy ($\text{ft-lb}/\text{ft}^2$) by hail size class for 1960-1961. Data from hail indicators were obtained from the Colorado State University hail network.

Size Class		1960				1961			
Median		VOLUME		ENERGY		VOLUME		ENERGY	
Diameter Inches	Cm	$\frac{\text{Cm}^3}{\text{Cm}^2}$	Per- cent	$\frac{\text{ft-lb}}{\text{ft}^2}$	Per- cent	$\frac{\text{Cm}^3}{\text{Cm}^2}$	Per- cent	$\frac{\text{ft-lb}}{\text{ft}^2}$	Per- cent
1/8	.32	.012	23	0.0#	0	.007	6	0.0#	0
1/4	.64	.014	30	1.6	22	.031	23	3.4	13
1/2	1.27	.011	22	2.4	32	.055	40	12.0	47
3/4	1.91	.004	9	1.0	14	.037	27	8.6	34
>1-1/8	2.86	.008	16	2.4	32	.005	4	1.5	6
Total		.049	100	7.4	100	.135	100	25.5	100

#Stones of this size do not dent the hail indicators.

TABLE 2

Comparison of total volume of hail and total impact energy from hail with area of sugar beets damaged from hail, 1960-1961.

Year	Volume of Hail $\frac{\text{Cm}^3}{\text{Cm}^2}$ (Table 1)	Impact Energy $\frac{\text{ft-lb}}{\text{ft}^2}$ (Table 1)	Total Acres of Beets Damaged by Hail#
1960	.049	7.4	41,428
1961	.135	25.5	124,634
Ratio $\frac{1961}{1960}$	2.8:1	3.4:1	3.0:1

#Mr. Lymon H. Andrews, Southern District Manager of Great Western Sugar Company of Denver, Colorado, writes as follows:

"In response to your inquiry . . . , I have asked our statistician to compile the following figures, which give in total the number of acres of beets that were hailed in the past three years, which includes all of Northern and Eastern Colorado, some acreage in Nebraska east of Julesburg, and in the Holdrege, Nebraska area:

1961	124,634 Acres
1960	41,428 Acres
1959	37,958 Acres

You will note that this checks very closely with your observations that three times as much total ice fell in Northeastern Colorado in 1961 as fell in 1960. 124,634 acres hailed, which includes acreage that was hailed more than once, is the largest damage suffered from hail in this district in many years."

3. Examination of the air-bubble and ice crystal structure of hailstones collected in 1960 and 1961 indicates that most of the volume of ice in hailstones grew in a "wet" environment (large crystals) as opposed to a "dry" environment (small crystals) [A, E]. This fact is considered significant from the standpoint of possible modification of hail, since it suggests that hail size, and hence damage, might be reduced by changing the phase of sub-cooled droplets from liquid to ice.
4. It is of some interest to compare the hail impact energy values obtained during the evaluation study in 1959 with comparable data for 1960 and 1961. Figure 1, extracted from [C], shows such a comparison. From Figure 1 it may be seen that the energy values (E_{max}) for the seeded cases for 1959 were slightly less than for the non-seeded cases for that year and were also less than the energy values observed for 1960 and 1961.
5. Procedures and equipment for the Colorado State University hail network have been developed into an operational network that is considered suitable for hail modification experiments when the final experimental design is completed.
6. The statistical properties of the hail data that would be of interest in final design of a

hail-modification experiment (variance, homogeneity, correlations between areas, etc.,) have not been examined, pending inclusion of data from 1962. The basic data have been placed on IBM cards, however, so that this type of analysis can be performed readily.

7. In addition to these findings, which are directly related to measurements of hail at the ground, data from the hail network were used as a basis for other studies of the local and synoptic-scale environment in which hail formed. Results from these studies include the following:
 - a. Hail occurrences are favored in a broad-scale synoptic environment in which a 500 mb "relative velocity maxima" moves through the latitude of hail occurrences in the high plains [D].
 - b. Movement of precipitation cells which contain hail tends to be clockwise from the 500 mb wind direction and with a velocity approximately that of the 500 mb wind [C].
 - c. The position of hailfalls with respect to precipitation areas does not follow a consistent pattern, but does suggest a process by which hail is concentrated into shafts of relatively small cross section. [B]

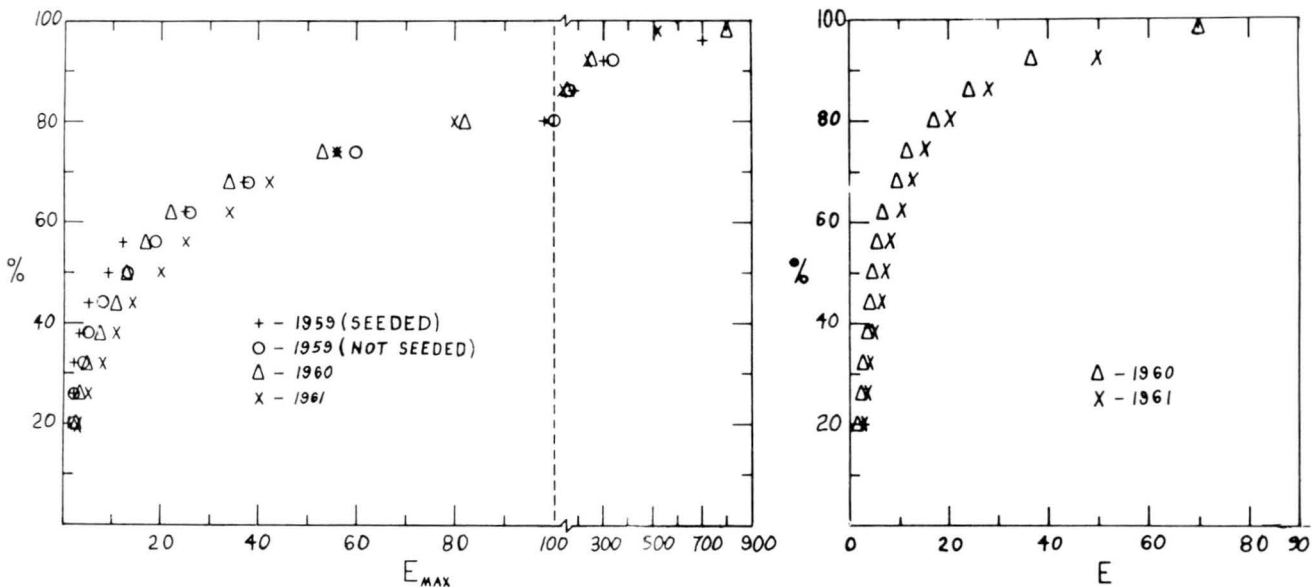


Figure 1. Cumulative frequency (percent) of hail impact energy values (ft-lb per sq ft). E_{max} values are computed on the assumption that all stones are of the largest size; E values are computed from observed size distributions.

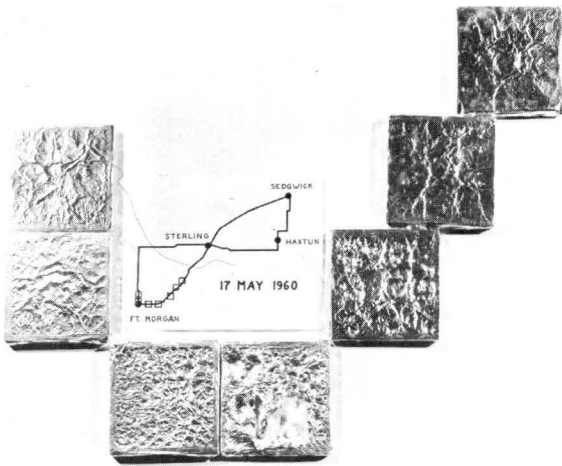
REFERENCES

(Not supported by NSF Grant 12139)

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| <p>1. Schleusener, Richard A. The 1959 hail suppression effort in Colorado and evidence of its effectiveness. Presented at the Verona Hail Conference, August 1960 and scheduled for publication in NUBILA.</p> <p>2. Schleusener, Richard A., and Paul C. Jennings. An energy method for relative estimates of hail energy. <i>Bul. Amer. Meteor. Soc.</i> 41(7): 372-376, July 1960.</p> | <p>3. Schleusener, Richard A. Hailstorm damage to crops in northeastern Colorado and an analysis of precipitation anomalies associated with a cloud-seeding program in 1959. <i>Journal of the American Society of Sugar Beet Technologists</i> 11(5): 413-428, April 1961.</p> |
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(Supported in whole, or in part, by NSF Grant 12139)

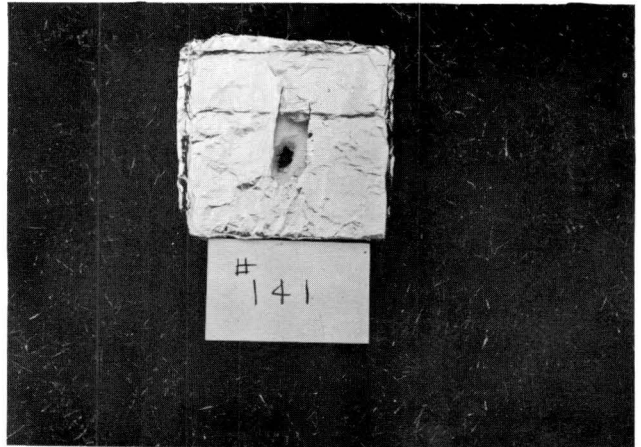
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| <p>A. Schleusener, Richard A. Hailstorm characterization and the crystal structure of hail. Prepared for AMS Monograph on Severe Local Storms. Extracted from remarks presented at Conference on Severe Storms, Norman, Oklahoma, 13 Feb 62. CER62RAS9.</p> <p>B. Schleusener, Richard A., and Thomas J. Henderson. Observational data on the position of hailfalls with respect to precipitation cells. Presented at AMS Conference on Severe Storms, Norman, Oklahoma, Feb. 1962 CER62RAS1.</p> <p>C. Schleusener, Richard A., and Lewis O. Grant. Characteristics of hailstorms in the Colorado</p> | <p>State University Network, 1960-61. <i>Proc. Ninth Weather Radar Conference.</i> p. 140-145, October, 1961.</p> <p>D. Schleusener, Richard A. On the relation of the latitude and strength of the 500-mb west wind along 110 degrees west longitude and the occurrence of hail in the lee of the Rocky Mountains. Prepared for AMS Conference on Severe Storms, Norman, Oklahoma, Feb. 1962, CER61RAS46.</p> <p>E. Eaton, L. R. Hailstone structure studies, 1960-61. Unpublished report, Colorado State University, November 1961.</p> |
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Hail indicators provided the basic data for estimates of hail intensity. The maximum depth of hail from the storm of 17 May 1960 was eleven inches near Fort Morgan, Colorado.



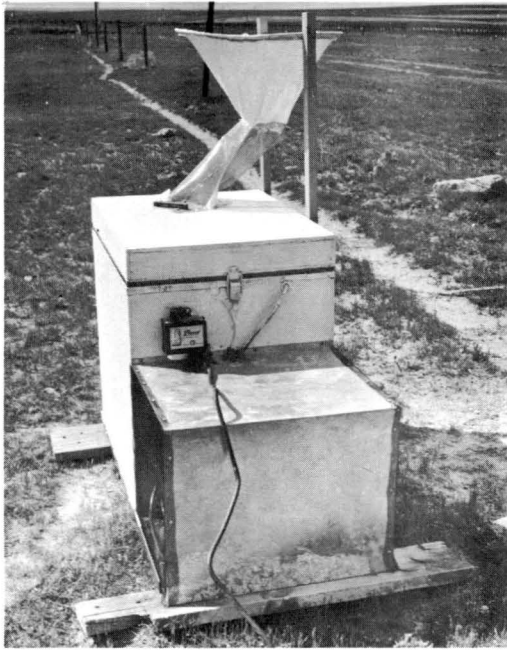
Hail drifts were more than knee-deep 24 hours after the storm of 6 July 1961 near New Raymer, Colorado.



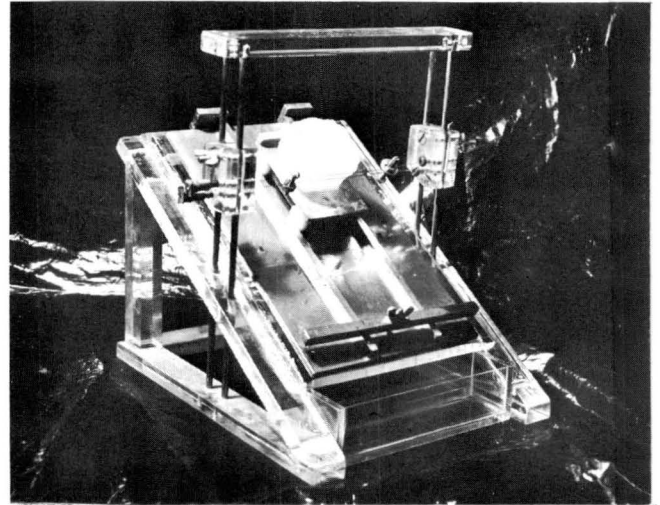
This photo shows the imprint from one hailstone on a hail indicator.



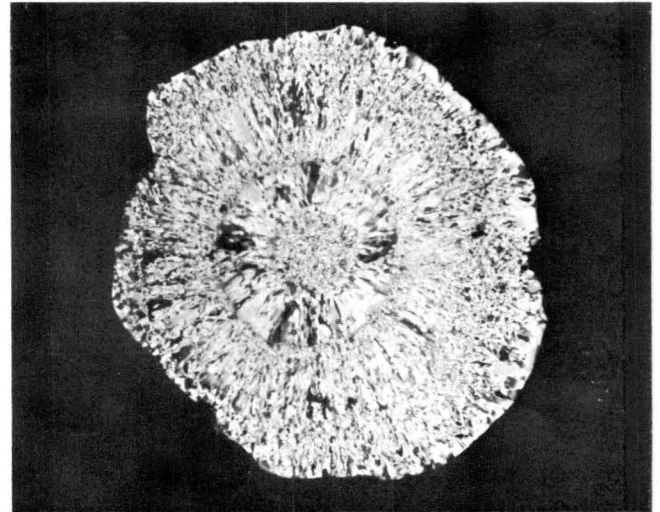
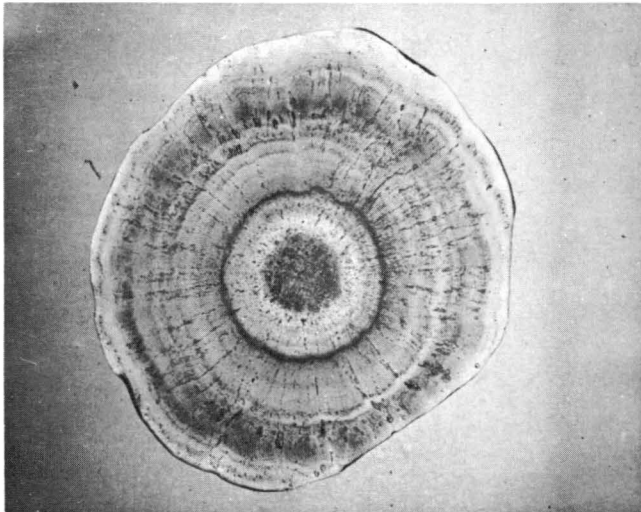
The intensity of this hailstorm was sufficient to remove the bark from the windward side of tree branches. (Synder, Colorado, 13 July 1962).



Mechanically-cooled hail collector boxes were used to supplement stone samples collected by volunteer observers.



Hot-wire device for obtaining thin sections of hailstones. (Stone to be sliced is frozen to small cart which rolls down inclined plane, bringing stone into contact with hot wires.)



Views of air bubble structure (left) and crystal structure (right) of a stone from the storm of 1 July 1961 near Yuma, Colorado. Air bubble structure was obtained from a section of approximately 2.5 mm thickness viewed under non-polarized light. Crystal structure was obtained from a section approximately 0.7 mm thick, viewed under polarized light.

NEWSLETTER No. 2

1962 SEASON

STUDY OF THE CHARACTERISTICS AND FORMATION OF HAIL

Colorado State University

Fort Collins, Colorado

Dear Cooperator:

The data collecting phase of our 1962 hail study project was conducted from 15 May - 1 August. Since the field phase ended on 1 August, no additional rain or hail reports are requested for this year.

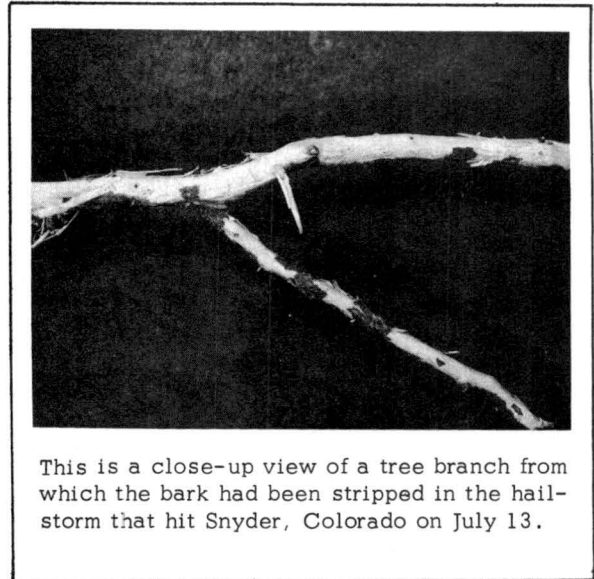
DATA COLLECTED

The amount and quality of data collected this season has been quite satisfying. From 15 May to 25 July, you and the other cooperators have sent in over 500 Reports of Hail Occurrence, and in addition, have saved over 125 separate samples of hailstones. More than 600 styrofoam and aluminum foil hail indicators were damaged from hail at the 125 locations at which we had the indicators. To complete our surface observations of hail, we had one man, Mr. Bob Rinker, whose full-time job has been to interview people along the paths of as many hailstorms as possible, which occurred in NE Colorado. Bob has investigated in detail more than 30 separate hailstorm paths.

This season we have had three radars in operation. Two radars are located just east of New Raymer and in addition we have had access to the CPS-9 radar at Lowry Air Force Base in Denver. Each of the radars was equipped with 16mm cameras to give radar information in permanent form.

To determine rates of growth and movements of convective cells we have used a pair of 5" x 5" stereo cameras, located about 10 miles northeast of Fort Collins. These stereo cameras are about 4-1/2 miles apart. Photos are taken simultaneously with both cameras pointed in the same direction. We now have almost 800 pairs of stereo photos.

To increase the density of meteorological measurements in the network we have had (at Buckhorn Mountain, Fort Collins, Nunn, Briggsdale, New Raymer, Sterling, and Holyoke) instruments which record wind speed, wind direction, sky brightness, relative humidity, and temperature on a continuous basis. In addition, we have made on storm days, 7 airplane flights measuring the vertical distribution of temperature, relative humidity, and pressure over Fort Collins, New Raymer, Sterling and Holyoke. These data will be used to better understand the dynamics of thunderstorms and hopefully to better forecast thunderstorms and hail occurrence.



This is a close-up view of a tree branch from which the bark had been stripped in the hail-storm that hit Snyder, Colorado on July 13.

CLOUD SEEDING

No extensive cloud seeding has been accomplished this season, although we did seed potential hail-bearing clouds from the New Raymer Airport on three days during the last week in July. The primary purpose of these tests was to check out procedures and a new silver iodide generator which has been developed by Professor Roger Steele. Next season additional seeding tests are planned.

We welcome back to Colorado State University and the hail study, 1/Lt. John Marwitz, a native of Brush, who graduated from Colorado State University in June 1959 and has just completed a tour of duty with the Air Force.

It is with deep regret that we learned of the recent death of Dr. Lyle Andrews of Nebraska State Teachers College in Chadron, Nebraska. Dr. Andrews had cooperated with the Colorado State University hail studies, and had been particularly concerned with physical studies of hailstones.

Thank you again for a job well done.

Sincerely yours,

Richard A. Schleusener

1 August 1962

From:

Civil Engineering Section
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Fort Collins, Colorado