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COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

SUMMARY OF DATA FROM TEST CASES OF
SEEDING THUNDERSTORMS WITH SILVER IODIDE IN
NORTHEASTERN COLORADO, 1962-63-64

by

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and

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Civil Engineering Section
Colorado State University

December 1964

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6 June	15 June	26 July
13 June	11 July	30 July
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6 July	22 July	
7 July	25 July	
8 July	26 July	
9 July		
27 July		
30 July		
31 July		

INTRODUCTION

Objectives

The objectives of the research on hail being conducted at Colorado State University are to continue the dynamic and physical studies of the significant factors in the generation and growth of hailstorms, and to determine the effects of cloud seeding on thunderstorms by a systematic attempt to modify thunderstorms.

This report summarizes the data from test cases of individual thunderstorms that were either seeded or not seeded with silver iodide in north-eastern Colorado during the summer seasons of 1962, 1963, and 1964.

Delimitation

This report does not include a summary of the dynamic and physical studies which were continued under this project, but includes only the summary of data from the test cases of seeded and non-seeded thunderstorms.

Because of the limited numbers of test cases to date, it is not possible at this time to draw conclusions concerning the effects of seeding on thunderstorms. The purpose of this report is to summarize the data from each test case in order to set a pattern for analysis of all test cases and to provide a record of the data from each test case during the 1962, 1963, and 1964 seasons.

DATA AND METHODS

General

Procedures used in 1962: Seeding was conducted on three days and on seven individual cells in 1962. The equipment used was an airborne non-combustion type silver iodide generator (Schleusener, Grant, and Steele, 1963). The primary purpose of the seeding experiments in 1962 was to develop procedures for a coordinated effort between the seeding aircraft and the associated observation equipment in the field, including the ground control radar, the field equipment, and observers.

Procedures used in 1963: There were five days in which individual thunderstorms were seeded in 1963, which included six individual thunderstorm cells. The equipment used for seeding was an airborne silver iodide generator, patterned after the Fuquay Model, using approximately 8.3 grams of silver iodide per minute. Some U. S. Navy Alecto units were used on 26 July. These consumed 1770 grams of silver iodide per minute.

The primary purpose of the seeding experiments in 1963 was to continue the development of procedures for coordination between the seeding aircraft and the ground observation systems, including the control radar and the associated ground observers. The concept of a mobile operation

evolved which lead to the finalized design for the experiments in 1964.

Procedures used in 1964: The experimental procedures for the 1964 season were designed to provide comparisons of physical parameters of the hailstorms at successive times, both for an interval before, an interval during, and an interval after the seeding of storms selected at random and for other control storms left unseeded (also selected at random) for corresponding periods. Differences between "target" and "control" storms are to be evaluated for significance after the accumulation of a significant number of cases. Schleusener and Marwitz (1963) suggested many of the basic techniques for the design of the data analysis.

On days for which hail was forecast, the seeding aircraft was placed on "stand-by". At the time of development of individual thunderstorms, the aircraft was ordered to be airborne and to get into position for possible seeding. The aircraft made measurements of updrafts and downdrafts in the thunderstorm being observed by radar during this preliminary time. When an echo was observed to exceed 30 KFT MSL, and at the same time to have had updrafts underneath the cloud exceeding 500 feet per minute, a decision order was given by the radar controller for the pilot to open a sealed

envelope containing a random decision to "seed" or "not seed". If the decision was to "seed" the storm, the pilot attempted to place the silver iodide in the strongest updraft of the storm and continued seeding until the storm dissipated, passed beyond radar range, or the aircraft and/or generator ran low on fuel. For a "no seed" decision the pilot remained airborne to observe during the same period of time as though seeding were actually taking place. In either situation the test cases were carried on for approximately one hour. The pilot and the observer on board the seeding aircraft were the only ones that knew at the time whether or not the cell was being seeded.

Ground observations included the following: radar tops, echo maximum reflectivity, elevation of maximum reflectivity, plan position track, and aerial coverage. Other ground observations made photographic records, both time lapse and conventional, of changes in cloud appearance. Field surveys determined the extent and intensity of hail, maximum stone size, estimated impact energy numbers and precipitation. Pilot balloons were sent up to determine air flow.

During the test case the seeding airplane was used to record various types of information. A running account was kept on the following items: altitude, outside air temperature, time, indicated airspeed, magnetic heading, power settings, gear and flap positions, G-meter readings, and vertical speed. The observer also took numerous 35 mm slides and 8 mm movies from the airplane. On occasional flights a Gardner condensation nuclei counter was carried. Following the termination of seeding or equivalent time for the "no seed" cases, the aircraft was used for aerial reconnaissance of areas of rain and hail on the ground.

An observation airplane was used in 1964 for most test cases. It carried an observer who took photographs and made observations of test cells being studied.

Voice radio was used for communication's between the seeding and the observation aircraft, the radar controller, and the ground observation crews.

The seeding aircraft was equipped with a special rate of climb device (IVSI, inertial-lead vertical speed indicator) that permitted estimates of updrafts and downdrafts. The IVSI data were combined with appropriate measures of aircraft airspeed, power settings, and configuration to obtain an estimate of vertical velocity. These vertical speed indications proved to be extremely valuable in determining whether or not the seeding aircraft was in the vicinity of an updraft and from this information it was possible to determine when the material released by the silver iodide generators was likely to be taken into the thunderstorm.

Comparisons were made between seeded and unseeded thunderstorms for time periods following the time when the airplane began seeding (or could have begun seeding for the no cases). In addition, adjacent cells were monitored for effects such as an increase in intensity that could result from an added downdraft from a neighboring seeded cell.

Test cases were selected on eight different days in 1964: four of these days provided "seed" test cases and three of these days provided "no seed" test cases. On the other day the decision was to "seed", but one generator became inoperative after experiencing severe turbulence and part of the other generator was lost in severe turbulence the day before, so this day was not considered to be a "no seed" test case.

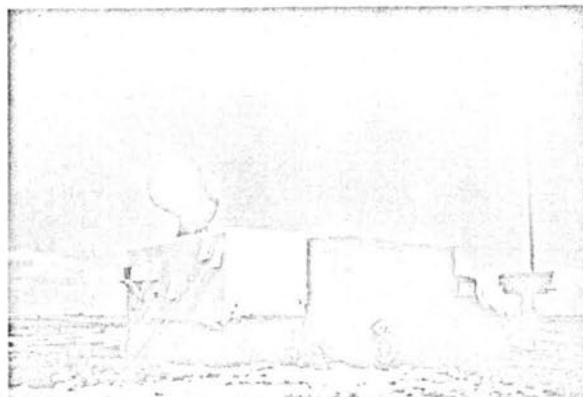
Also during the 1964 season there were two additional days of seeding. The operation during these days consisted of seeding a small cumulus cloud and observing it for any effects. These two days are included in this summary report.

The majority of the information contained in this report is derived from a study of the test cases in 1964. The description of the data used applies primarily to the data gathered in 1964. For 1963 and 1962 much of the same type of data as was obtained is included herein for a record of the seeding efforts.

Some of the Equipment Used on the Project



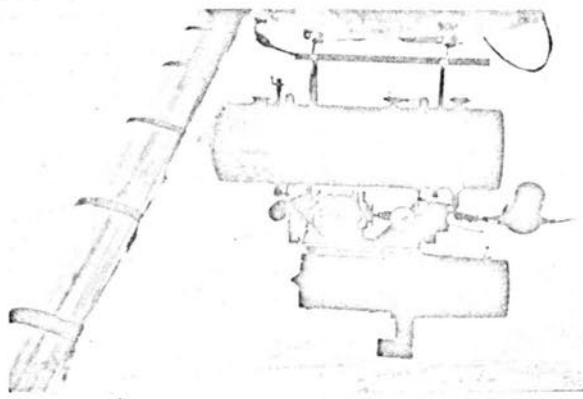
New Raymer radar site, 1/2 mile east of New Raymer, Colorado. This site was used during the 1962, 1963, and 1964 seasons.



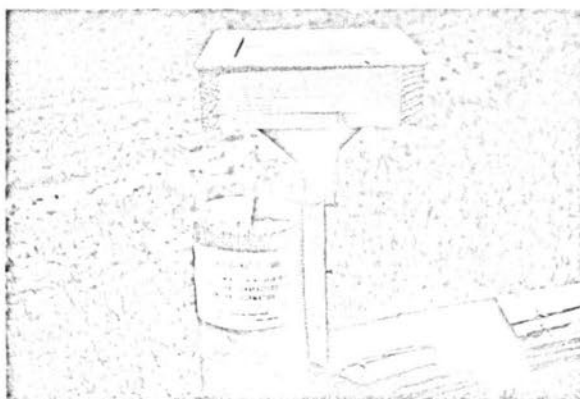
M-33 radar site, 10 miles east of Fort Collins, Colorado. This site was used during the 1962, 1963, and 1964 seasons.



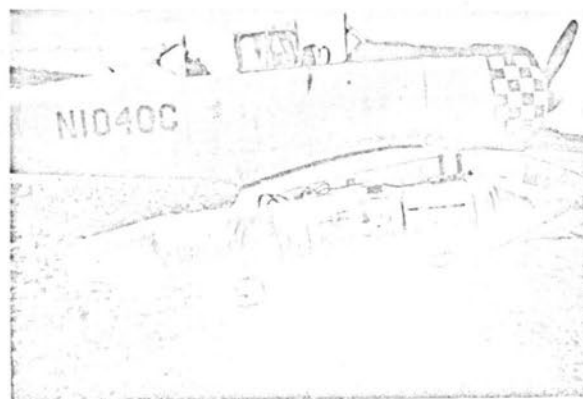
U.S. Navy Alecto units being fired. These were used to seed the 26 July 1963 test case.



Fuquay generator in flight. This unit was used during most of the 1963 season.



A hail energy indicator. Approximately 100 were used in 1962; 75 in 1963 and 1964. These are scattered throughout the test area in northeastern Colorado.



Lohse generator attached to a seeding airplane. Two of these units were used in the 1964 season.

Test case

General description: A short table listing information pertinent to each test case is given at the beginning of the appendices pertaining to the test case. This table identifies the test case and describes what seeding was accomplished.

Summary table: Each test case has a summary table which includes nine parameters and breaks them down with respect to time. The time periods are broken down into intervals "before", "during", and "after" each test case. During the given time period the data are averaged and the total number of readings averaged is noted after the average. NA indicates that there was no data available during this particular time period.

These tables are designed to show obvious changes in selected parameters. The parameters selected are those believed to measure significant differences between thunderstorms, and represent measurements within the present measurement capability.

The time intervals were selected to be about one-half hour long. The test case time was divided into four parts, the middle two representing the time interval "during" the test case. The first one-fourth of the test case plus fifteen minutes prior to the test case represents the "before" period. The last one-fourth of the test case time plus fifteen minutes represents the "after" period. One exception to this is the vertical velocity which has its test case time period divided into three parts. The thirds represent the "before", "during" and "after" periods.

Significant features: The significant features section of each appendices is a composite of many of the personal observations made by the many people working on the project. The data taken for each test case were also analysed and any obvious significant factors were noted in this area.

Synoptic data (Figures A-G): Surface weather maps are presented for 1100 MST for the test case date, and for the following day. These weather maps show the positions of high and low pressure centers and frontal systems. The 500 millibar map and the 300 millibar map for 1700 MST with jet streams are shown for all test case days. The precipitable water amounts for 1700 MST and the regions of the United States in which precipitation occurred during the 24-hour period ending 2300 MST are also shown.

The adiabatic diagrams (Skew-T diagrams) for Denver at 0500 and 1700 MST and, when available, the adiabatic diagrams for Fort Collins are presented. Upper-level winds for Denver are shown at the appropriate level on the adiabatic diagrams.

All of the above charts, except the Fort Collins adiabatic diagrams, are reproductions of official U.S. Weather Bureau data. The adiabatic diagrams for Fort Collins are taken from ozone-sonde data obtained at Fort Collins.

Photographic index (Figure II): A photographic index is given which shows the geographic locations from which the photographs were taken and an identifying letter and number for each photograph. The number indicates the time (MST) when the photograph was taken. The letter identifies the person who took the photograph: S (R. A. Schleusener), D (J. A. Donnan), A (August Auer) and M (J. D. Marwitz). A shaded triangle over the identifier indicates that the picture is published in this report. Selected photographs are shown to illustrate pertinent features of the cloud development during the test case day. These photographs were originally taken as 35 mm color slides.

For instance on 8 July 1964, S-1159 is a picture taken by R. A. Schleusener at 1159 MST. The location from which the picture was taken and the direction the camera was pointed can be determined from Fig. H, the photo index. This particular picture is published in the selected photos section for 8 July 1964 as is indicated by the shaded triangle.

It is noted that on some of the photo index maps there appear radar PPI (Plan Position Indicator) plots. These are given for test case echoes only so that one may relate the PPI radar plot to what is shown in the photographs which are taken of that particular thunderstorm echo.

There are also available a number of time lapse movies taken from the New Raymer radar site and the M-33 radar site. A limited amount of 8 mm movies are available covering interesting items observed from the seeding airplane.

Radar data (Figure I): The radar plan positions of individual radar echoes are shown, when available, for each day's operation. The plan positions of individual cells are shown at approximately one-half hour intervals during a three hour period centered on the test case. The data are a combination of the data from the New Raymer radar and the CPS-9 radar. The radars were operated in a manner suggested by Schleusener (1962). The maps were plotted by observing the PPI pictures from both radars simultaneously and interpolating when necessary. For some cases, one or the other radar was completely attenuated on the test case, so the data from the other radar had to be used with no aid to plot the radar echo position maps.

Time cross-section (Figure J): The data observed and measured during the time of observation of each individual test case thunderstorm are presented as a time cross-section. These

time cross-sections include various measurements that were made with the radars and by the field observers. The changes with time of each of the various parameters are shown.

Most of the terms used on the time cross-section graphs are self explanatory. The Z values noted on the CPS-9 data are reflectivity factors; Z_{max} is the maximum reflectivity and altitude of maximum Z is the altitude (MSL) of the maximum reflectivity factor (Z). Z_{20} gives the reflectivity factor at 20,000 feet MSL. The reflectivity units for Z are mm^6/m^3 . The values for Z are given as $10 \log Z$ (i. e. $Z = 10^3$ is listed as 30).

Track of seeding aircraft (Figure K): The track of the seeding aircraft is presented on the common map scale for overlaying on all other maps of northeastern Colorado. The track was recorded from visual observations by the observer during the flight.

The beginning time and ending time of each operation is noted on this map. The beginning time has a prefix of O (i. e., O-1629) and the ending time has a prefix of X (i. e., X-1729).

Track of observation aircraft (Figure L): The track of the observation aircraft is presented on the common map scale for overlaying on all other maps of northeastern Colorado. This track also was recorded from visual observations of the observer during the flight.

Rainfall and hailfall data (Figures M-O): Daily rainfall and hailfall amounts for the test case day are presented in the appendices for each test case day. The plotting scheme for rainfall was suggested by Marwitz (1964). Isohyetal maps of thunderstorm rainfall were drawn by viewing both the radar film and the rain gauge data. Times of first precipitation beginning along the transections (dashed lines) were obtained from the radar data and are noted on the maps. From these maps, time series of "path rainfall" were computed. "Path rainfall" is given in units of acre-feet by assuming the width of each transection to be 208 feet. Mean "path rainfall" for before, during and after seeding was taken from these time series and is presented in the summary tables for each test case.

The system used on the hailfall maps is as follows:

E = impact energy, ft-lbf/sq. ft.
S = maximum stone size, inches.
M = missing data.

○	$E < 10$	○	$0 < S < \frac{1}{4}''$
◐	$10 < E < 100$	◐	$\frac{1}{4}'' < S < \frac{1}{2}''$
●	$E > 100$	◑	$\frac{1}{2}'' < S < 1''$
		○	$1'' < S < 2''$
		◒	$S > 2''$

The hailfall map plotting scheme followed Schleusener (1961).

The rainfall and hailfall data were obtained from a number of sources which were as follows:

1. A network of cooperators in northeastern Colorado.
2. The Colorado State Patrol.
3. The Great Western Sugar Company observers.
4. A network of rain and hail gages maintained by this research project.
5. A mobile observer sent into the field to observe the particular test case.

There is also a map for each test case day which shows the estimated limits of the area in which precipitation is believed to have fallen from the test case thunderstorm. This map was drawn from the radar echo position maps, so is subject to the errors present in these data.

Location identifier (Figure P): A map showing the location of various geographic features is included for reference to better identify the positions of the seeding and observation airplane tracks and associated rainfall, hailfall, and radar data. All maps in this report that cover northeastern Colorado are on the same map scale and cover the same geographical area.

The three radar facilities used on the project are located on the location identifier map. Range circles are drawn around each radar to indicate its range capabilities. The New Raymer Radar has 20 statute mile range circles, the CPS-9 has 25 statute mile circles and the M-33 has 20 nautical mile range circles.

RELATED STUDIES BEING CONTINUED

Several related studies will either continue or begin during the 1965 project. Each study will attempt to explain the physical and dynamic charac-

teristics of the northeastern Colorado thunderstorm so that a more effective seeding effort can be accomplished. The following are some of the studies:

1. The relationship between radar and visual tops of thunderstorms is being studied with the aid of the modified M-33 radar system.

2. The relationship between thunderstorm tops and the environmental sounding is being studied. To date soundings from Denver and occasionally Fort Collins have been available. During the 1965 season, it is planned to launch regular soundings from New Raymer.

3. Thunderstorms in the high mountains of Colorado will be studied with the aid of an SO-12 radar located atop Chalk Mountain (elevation 12,200 feet) near Climax, Colorado

4. During the 1965 season, the relationship

between the environmental wind field and the thunderstorm genesis area, direction of motion and wind field will be studied. This study will be performed using a 15 station pibal network.

5. The relationship between lee waves and thunderstorm genesis areas will be studied using constant volume balloons tracked with the M-33 radar.

6. A study of the updrafts and downdrafts located in the base of the thunderstorm will be continued. It is necessary to know where the strongest updrafts are occurring so that the seeding material can be dispersed in this area and be drawn directly into the cloud.

SUMMARY OF PROJECT

Each of the individual test cases is summarized with respect to a number of different parameters. A summary of all of the summaries in the appendices is given below.

This summary includes both the seeded and

non-seeded cases. There is no distinction in this summary between the seeded and non-seeded cases. It is noted however that the nineteen test case days, there were only five days during which there was no seeding.

Summary of Nine Parameters for Test Case Days 1962, 1963, 1964

Test Case Characteristics	Prior to test case				During test case				After test case			
	Mean	No. Days	No. Data	Standard Deviation	Mean	No. Days	No. Data	Standard Deviation	Mean	No. Days	No. Data	Standard Deviation
Maximum diameter hail, inches	0.70	11	11	0.60	0.61	8	8	0.44	0.38	4	4	0.42
Maximum energy no., ft-lb/ft ²	370.	6	6	630	60	5	5	50	140	3	3	280
Radar tops K-ft MSL, M-33	44,800	3	12	16,000	44,600	4	29	14,500	38,100	3	11	11,800
Radar tops K-ft MSL, CPS-9	37,300	9	12	8,600	36,800	10	18	6,300	37,900	7	10	5,800
Radar tops K-ft MSL, NRR	36,300	11	15	6,100	35,600	10	22	9,800	37,900	7	13	11,100
CPS-9 radar reflectivity, Z ₃₀	35	7	9	9	36	9	15	9	35	6	8	6
Area covered by radar echo, mi ²	210	15	16	150	270	13	19	200	280	15	16	240
Rainfall-volume, acre-ft	13.9	--	14	8.5	14.4	--	13	9.1	15.9	--	12	9.9
Maximum updraft, ft/min.	800	11	35	500	500	10	39	400	400	8	25	400

RESULTS AND CONCLUSIONS

With the limited number of test cases available, it is not possible to form any conclusions concerning the effectiveness of cloud seeding in reducing hail damage. In this report, an attempt has been made to present the pertinent measurements taken of the development of a number of hailstorms so any obvious changes from the weather modification experiment might be delineated.

It is noted that this method of analysis, along with the planned improvements and expansions,

should provide a means by which the dynamic and physical factors governing the generation and growth of thunderstorms may be studied in detail.

From this limited number of test cases, there is no obvious consistent difference between the "seed" and "no seed" cases. The one possible exception being 26 July 1963. On this day there appeared to be "explosive" growth as a result of heavy seeding.

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- Marwitz, John D. , 1964: Autocorrelation and regional correlation of summer rainfall. Thesis for a Master of Science Degree in Civil Engineering, Colorado State University, Fort Collins, Colorado.
- Schleusener, Richard A. , 1961: Analysis of synoptic data for selected hail days in northeastern Colorado. Final Report, NSF Grant G-17964.
- Schleusener, Richard A. , 1962: Preliminary study of the relations between hail and thunderstorm reflectivity structure. Prepared during a 15 day active duty tour at Det 6, 24th Weather Squadron, Lowry Air Force Base 30, Colorado.
- Schleusener, Richard A. , Lewis O. Grant and Roger Steele, 1963: Preliminary tests on a non-combustion type silver iodide generator. Proc. 31st Annual Western Snow Conference, p. 122-131.
- Schleusener, Richard A. , and John D. Marwitz, 1963: Analysis of data of hailfalls as background for the design of an experiment in hail modification. Conference Review for Third Conference on Severe Local Storms, Urbana, Illinois.

TEST CASE OF 6 JUNE 1964

Test Case Began 1642 MST, Ended 1742 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 7.7 gms/min. Equipment Used: Lohse Generator

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	39,800	5	NA	0
Radar tops K-ft MSL, CPS-9	38,000	1	33,500	2	30,000	1
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	38	1	28	2	29	1
Area covered by radar echo, mi ²	136*	1	218*	1	156*	1
Rainfall-volume, acre-feet	4.6		9.3		11.8	
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

*Attenuation

SIGNIFICANT FEATURES

The surface weather map showed a weak pressure gradient over Colorado at the beginning of the period, with a deep low developing over the northern Rockies and moving to central Wyoming by the following day. Wind flow at the 500 mb level was primarily west to east with a jet stream entering the California coast and extending into western South Dakota. A thin overcast covered the area in the morning which cleared later and cumulus activity began in the early afternoon.

The M-33 radar was not functioning properly and there was no observation plane flight for this test case.

Radar data from the M-33 was very limited but it did get a 3,000 foot increase in tops during a 13 minute period following the beginning of seeding. New Raymer radar was missing tops information

because the echo was too close to the radar. The area of the radar echo and the rainfall volume increased as the test case progressed.

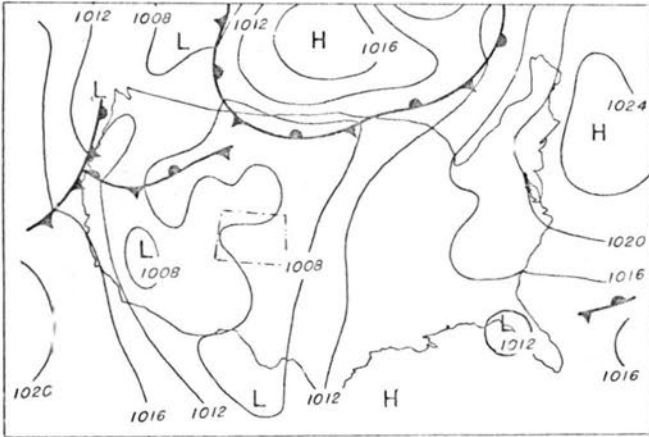
There was no upair data obtained with the seeding aircraft on this flight because the IVSI was not yet installed. The cell was seeded with only one generator.

This cell changed its longitudinal orientation from north-south to east-west. This led the radar observer at New Raymer to believe that we had seeded the cell since all other cells in the area maintained their north-south orientation.

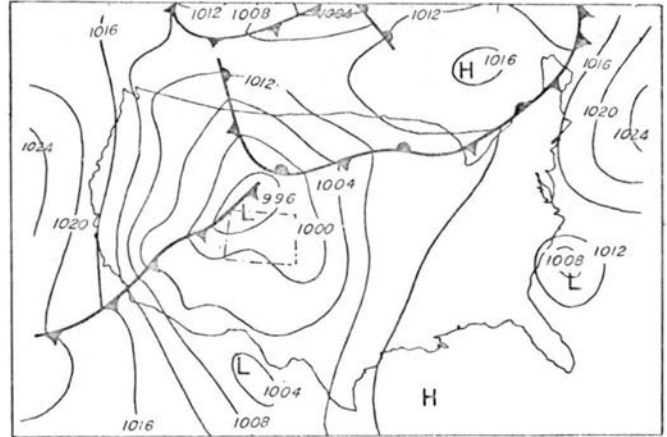
By mid-afternoon, a number of cells had built in that area to the east and south of New Raymer. Most of these echoes developed tops in excess of 30,000 feet.

6 June 1964
U. S. Weather Bureau Synoptic Data

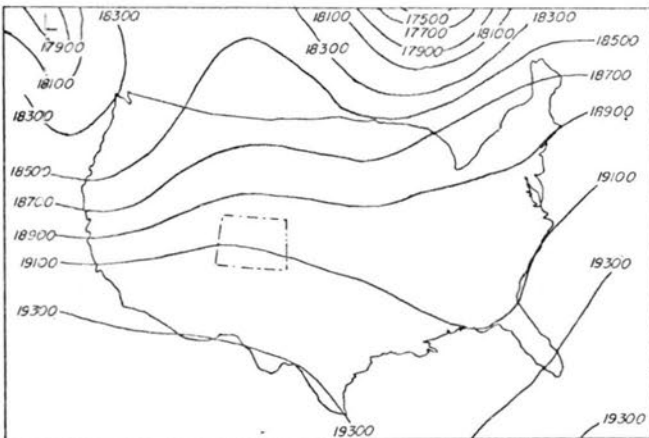
Figures A - F



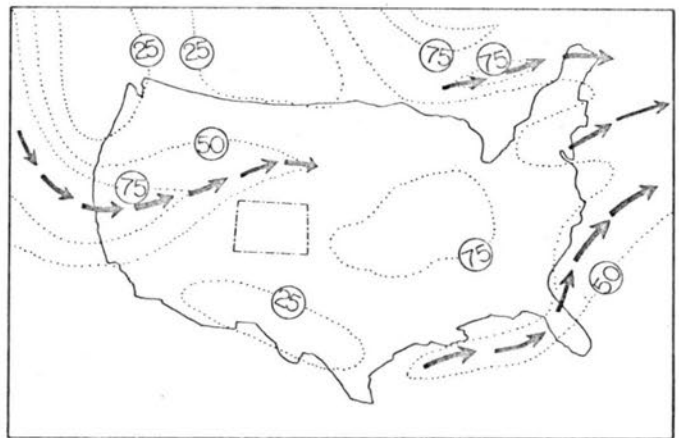
A. Surface Weather Map, 1100 MST (day of test case).



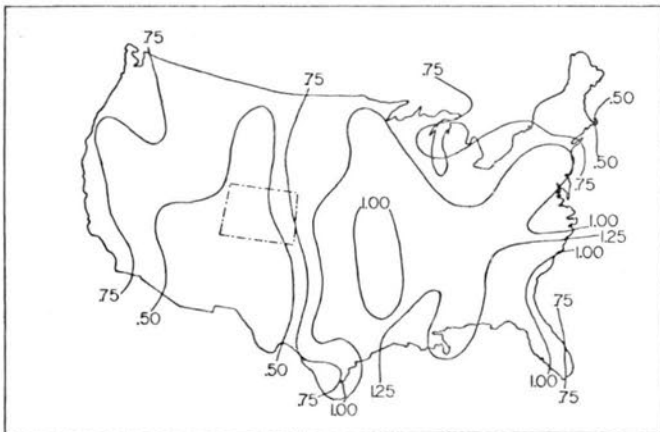
B. Surface Weather Map, 1100 MST (day following test case).



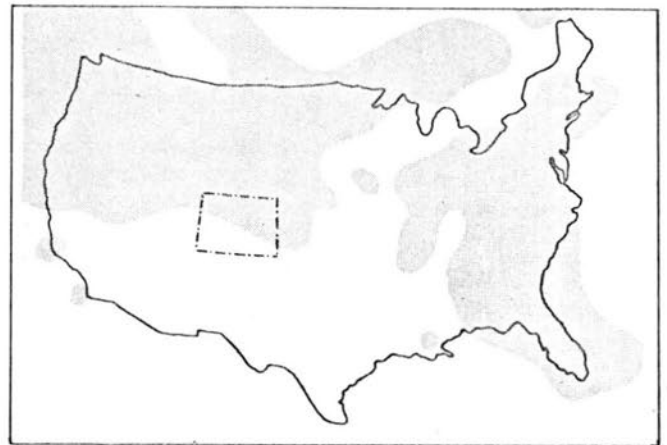
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



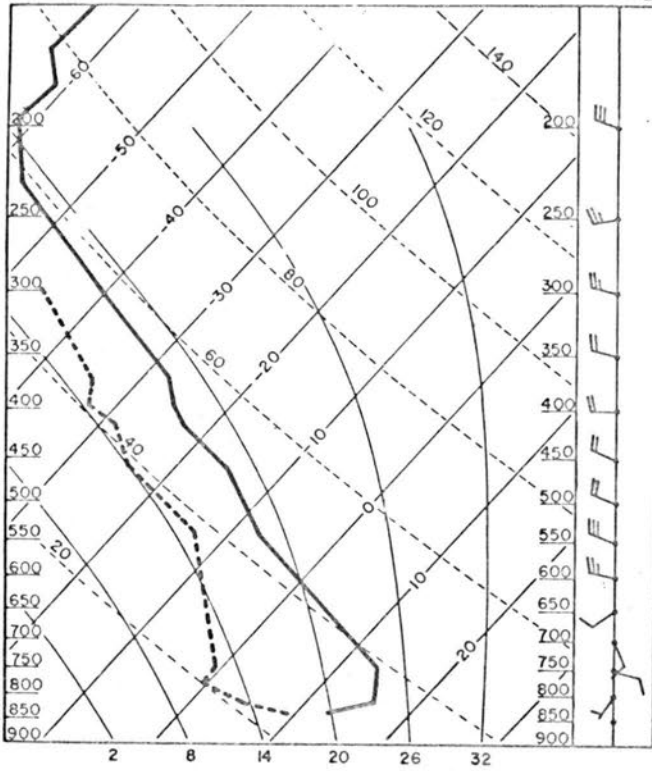
E. Precipitable Water, Inches, 1700 MST.



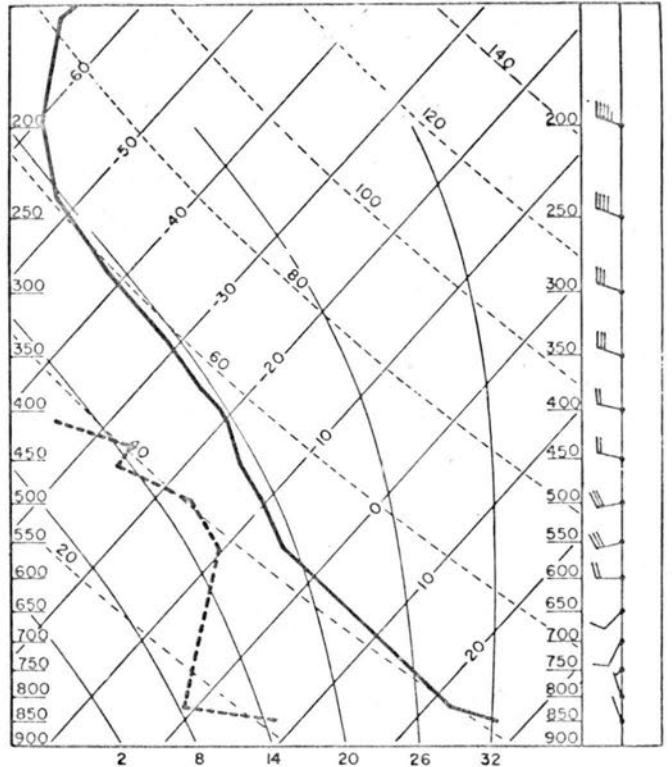
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

6 June 1964
Upper Air Soundings
Skew-T Diagrams

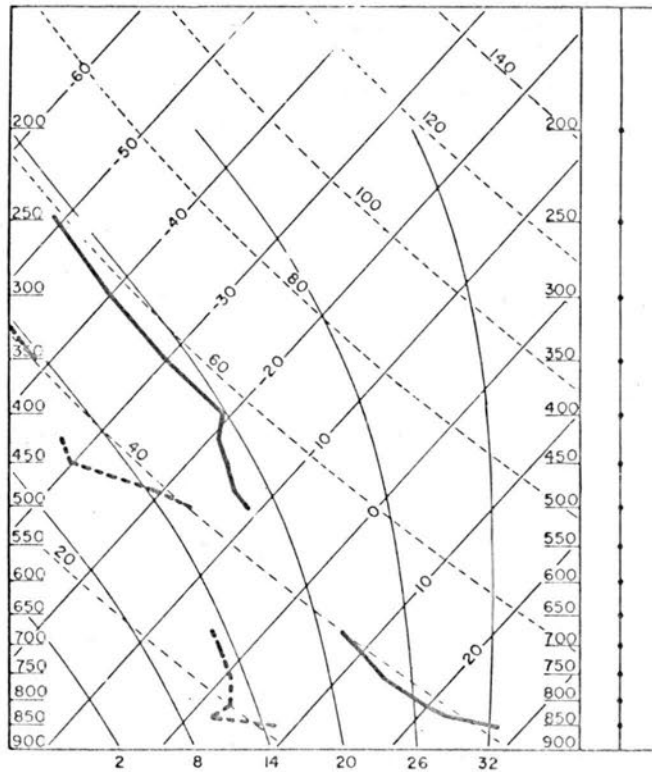
Figure G



1. Denver, 0500 MST.



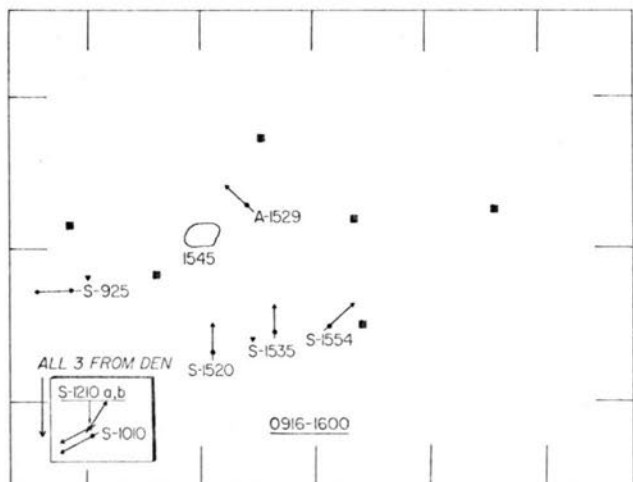
2. Denver, 1700 MST.



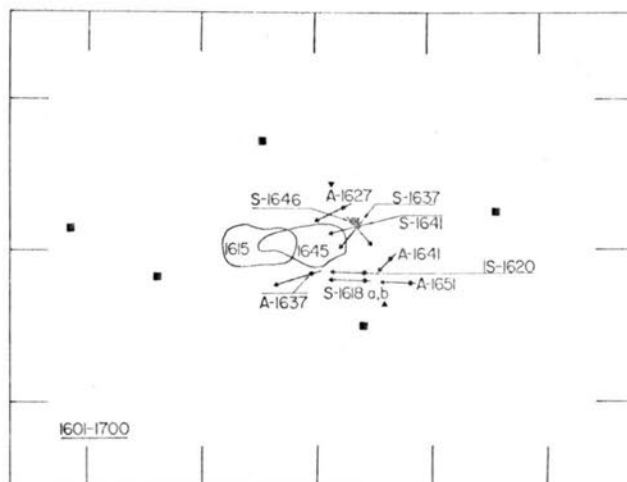
3. Fort Collins, 1300 MST.

6 June 1964
Photo Index

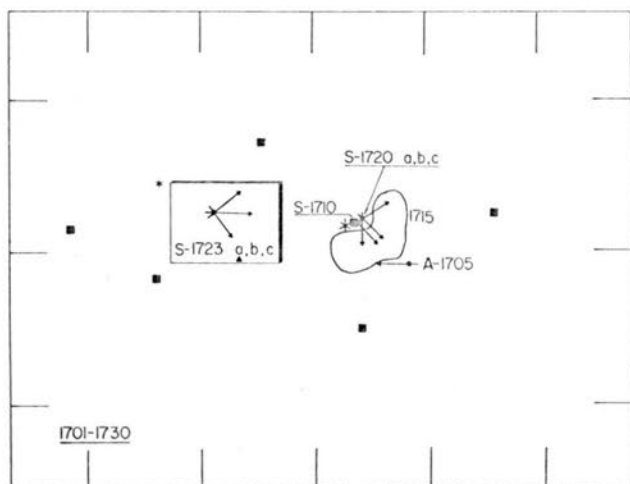
Figure H



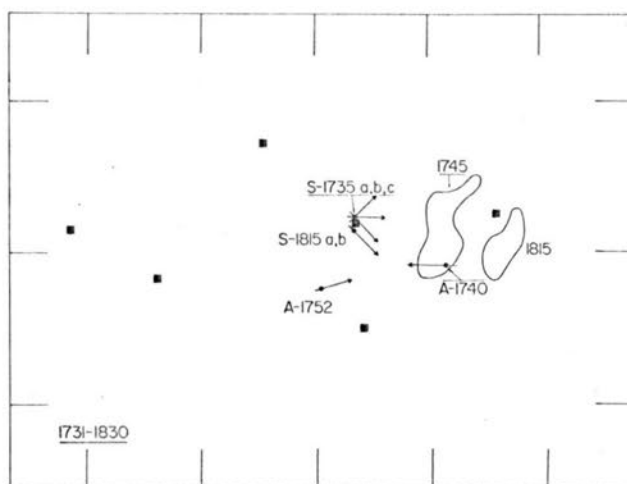
1.



2.

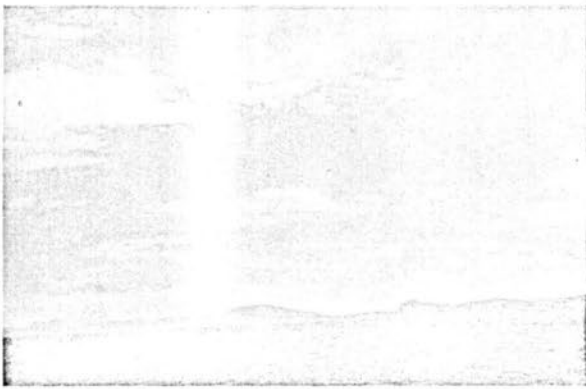


3.



4.

6 June 1964
Selected Photos



S-0925 General cloud pattern over mountains early in the day.



S-1535 Looking at the south side of what is to become the test case, one hour and seven minutes before test case began.



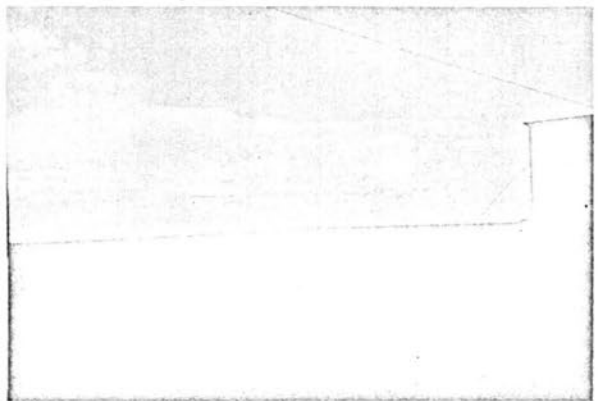
S-1618b Looking west at the relatively small test case twenty-four minutes before beginning.



A-1627 General picture of the test case from the seeding airplane.



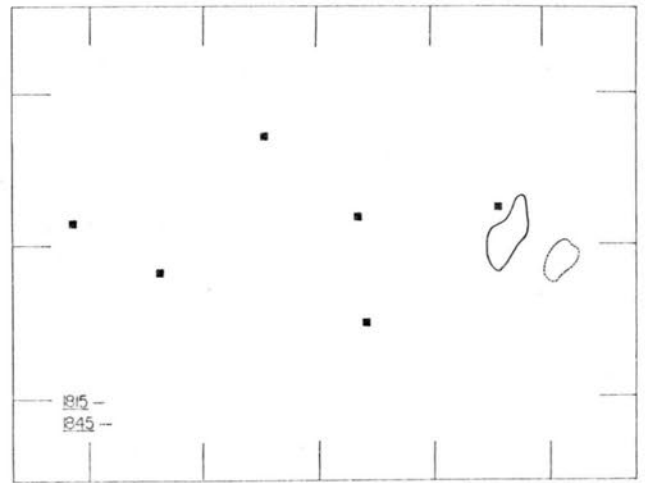
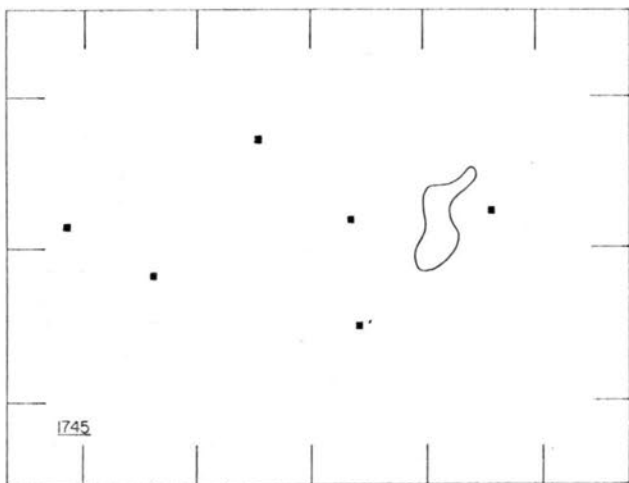
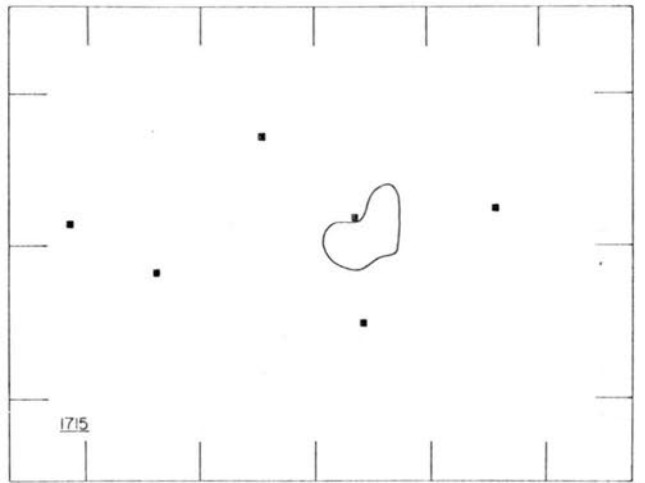
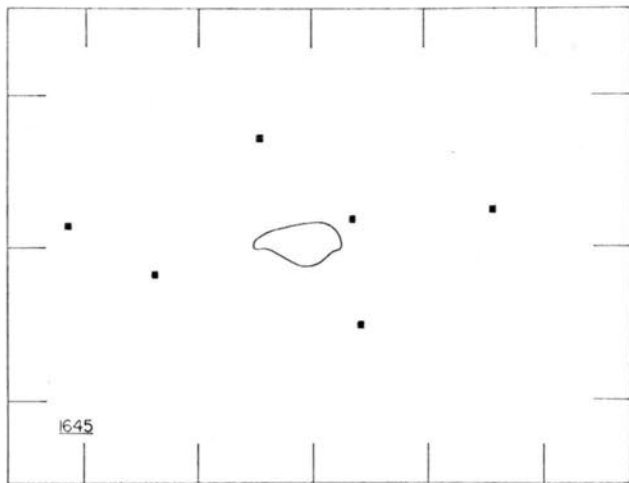
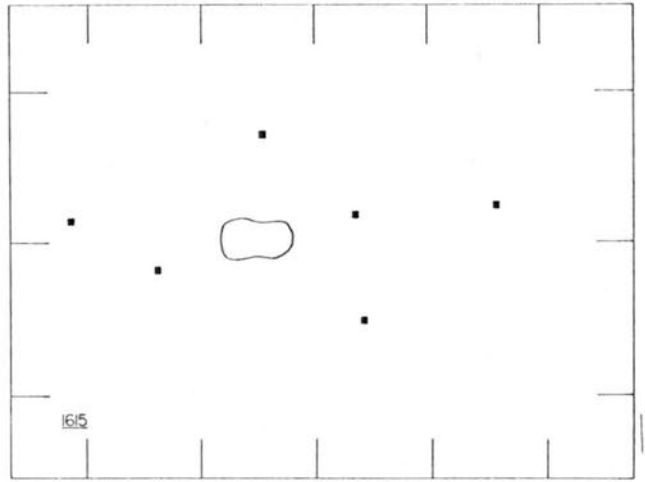
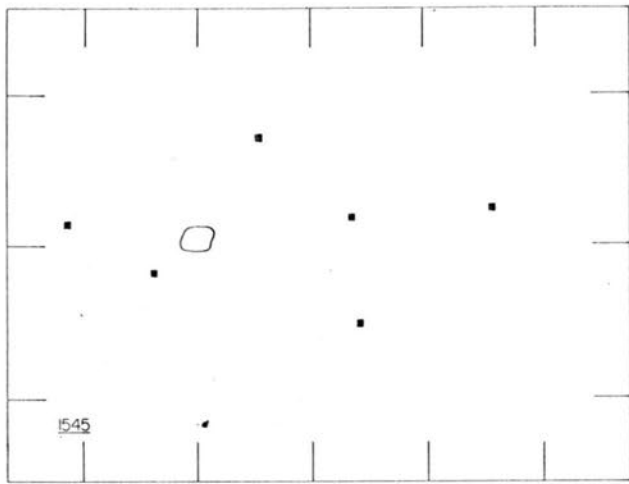
S-1723a Looking northeast from New Raymer at the rear of the test case. Rainbow lower right.



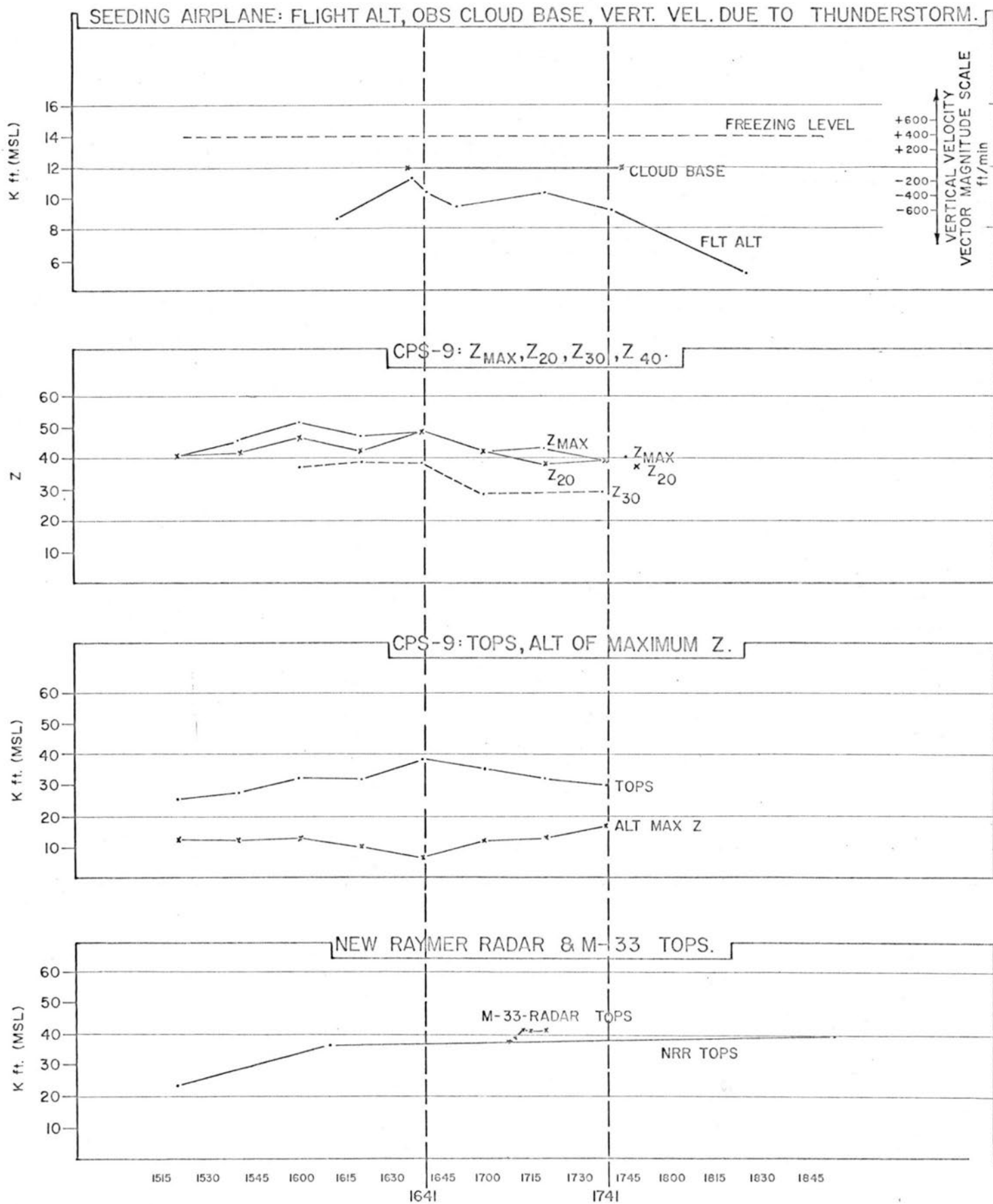
S-1815 Looking southeast from New Raymer at test case.

6 June 1964
Radar Echo Positions

Figure I



6 JUNE - 1964
 FIGURE J



TEST CASE OF 13 JUNE 1964

Test Case Began 1441 MST, Ended 1540 MST
 Seeded: NO Material Used: None
 Rate of Seeding: None Equipment Used: None

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	29,500	2	28,714	7	26,000	5
Radar tops K-ft MSL, CPS-9	NA	0	37,000	2	41,500	2
Radar tops K-ft MSL, NRR	38,000	1	37,667	3	NA	0
CPS-9 radar reflectivity, Z30	NA	0	35.5	2	38	1
Area covered by radar echo, mi ²	NA	0	698*	2	694*	1
Rainfall-volume, acre-feet	19.7		38.4		29.6	
Maximum updraft, ft/min.	2,000	2	NA	0	NA	0
*Attenuation						

SIGNIFICANT FEATURES

Northeastern Colorado remained north of a stationary frontal system through all of the test period. The 500 mb pressure pattern showed a sharp trough in western Colorado. The jet stream entered the Pacific coast near Oregon extending to New Mexico to the northern Great Lakes. The development of cumulus clouds on this date followed a pattern of development from clear skies early in the morning to rapidly growing cumulus clouds by mid-morning, changing to overcast skies as the squall line moved east from the Rocky Mountains.

The cumulus activity steadily increased ahead of the squall line during the afternoon resulting in significant thunderstorms in some areas of eastern Colorado. Hailstones, 2 to 3 inches in diameter, were reported at Burlington, Colorado, about 80 miles southeast of Fort Morgan. An Angus bull was reported killed by the hail in this area.

All equipment and personnel were in the field during the test case and functioned properly. We still did not have an observation airplane so there were very few aerial photographs taken. The available photos from the surface give a good display of

the developing and approaching squall line.

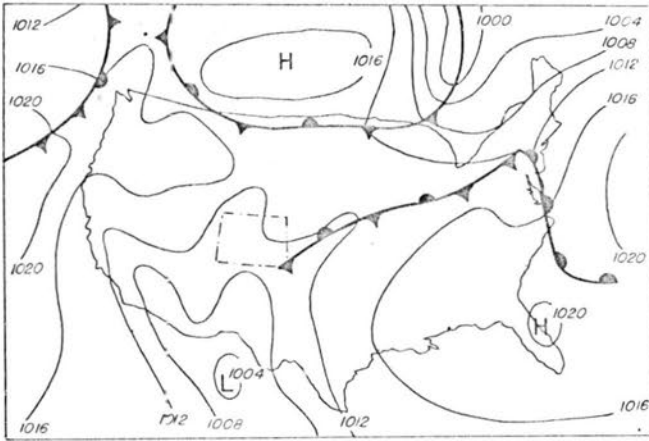
The New Raymer radar and the CPS-9 both gathered data on this test case. During the test case, the tops and the reflectivity both increased slightly.

Since there was a well developed squall line, the bases of the portion selected as a test case varied quite a lot and there were some areas of very severe updrafts. The +6,000 feet per minute given on the time cross section is a measurement that is not well substantiated, since it was taken from a standard rate of climate indicator. An area of dark green was noted on the south end of the test case. This is often associated with areas of hail and the observation is confirmed by the hail reports given in Figure O.

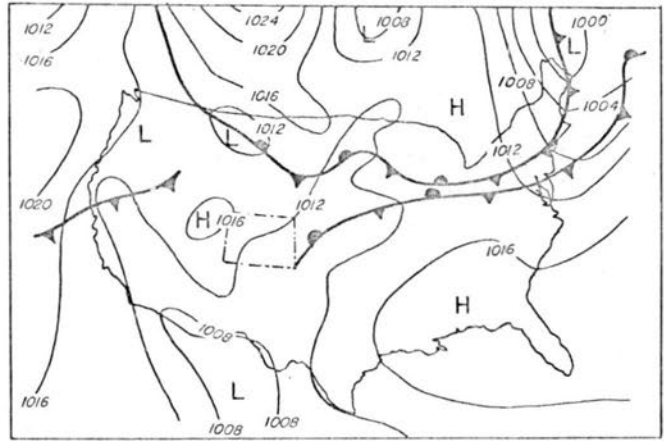
This test case in particular and the squall line in general produced quite a lot of rain and hail over the area as can be observed from Figures M and O. The rain and hail continued through most of the night over northeastern Colorado and proceeded into Kansas and Nebraska.

13 June 1964
U. S. Weather Bureau Synoptic Data

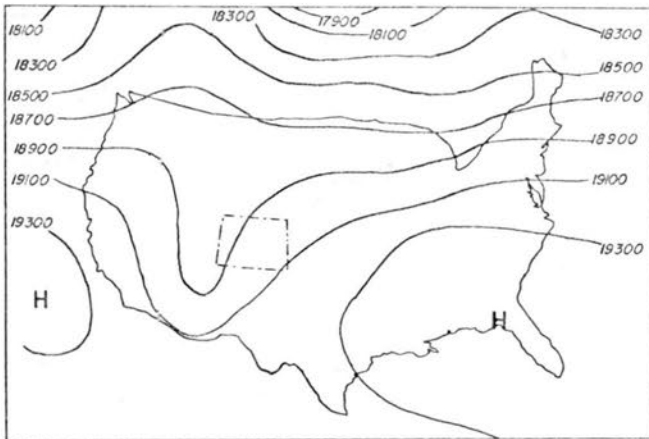
Figures A - F



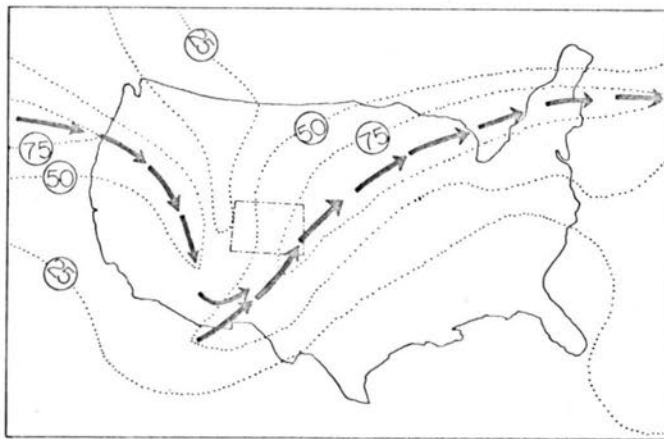
A. Surface Weather Map, 1100 MST (day of test case).



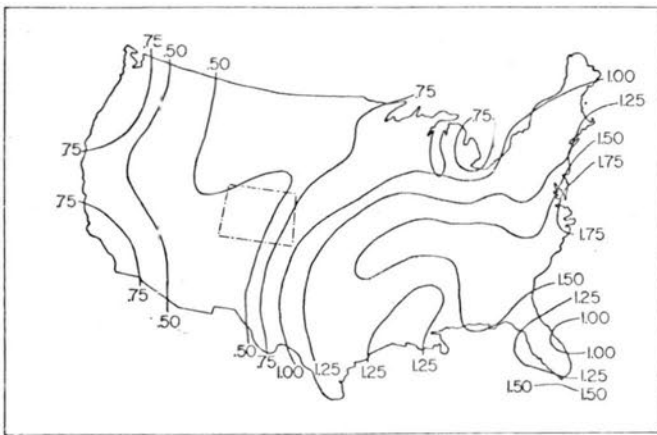
B. Surface Weather Map, 1100 MST (day following test case).



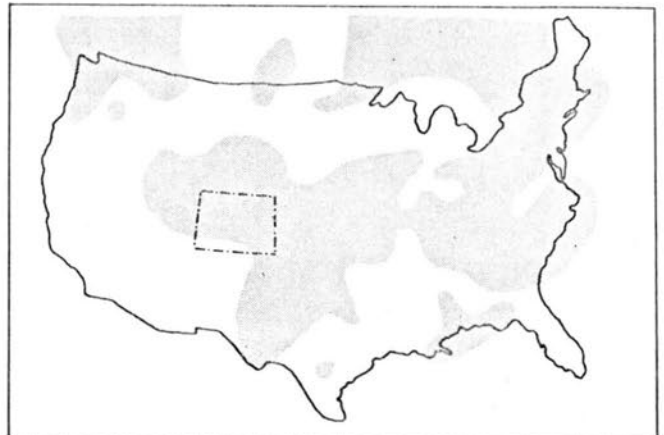
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



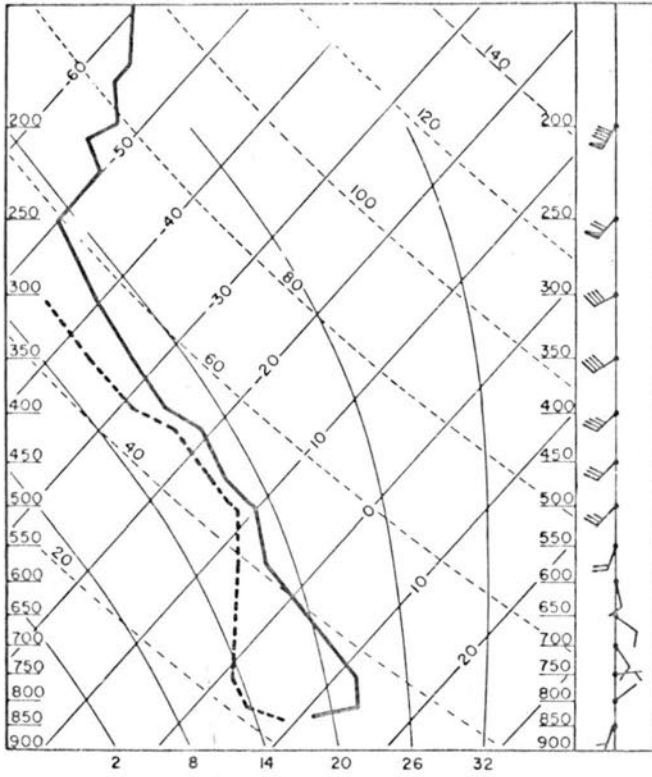
E. Precipitable Water, Inches, 1700 MST.



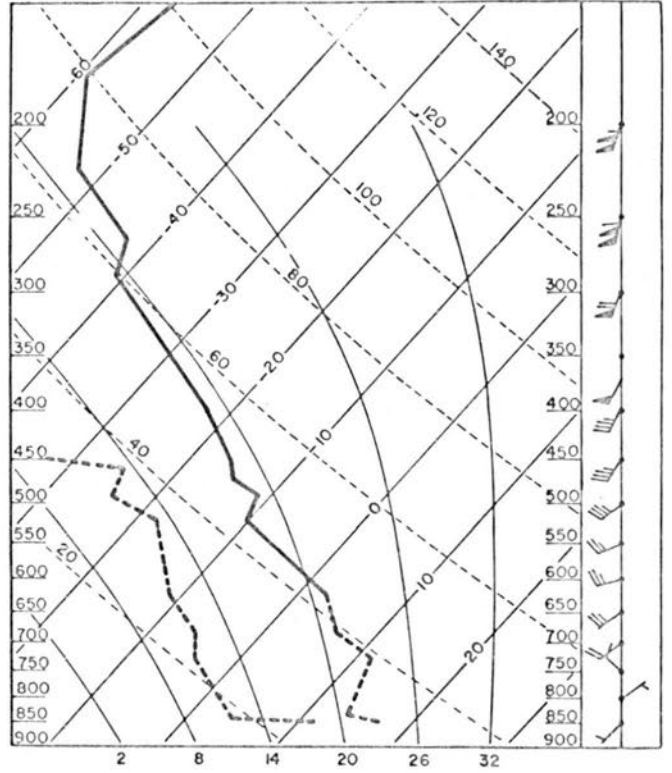
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

13 June 1964
Upper Air Soundings
Skew-T Diagrams

Figure G

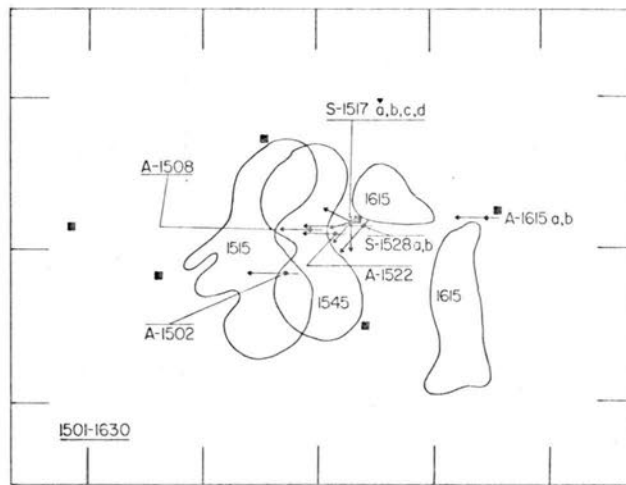
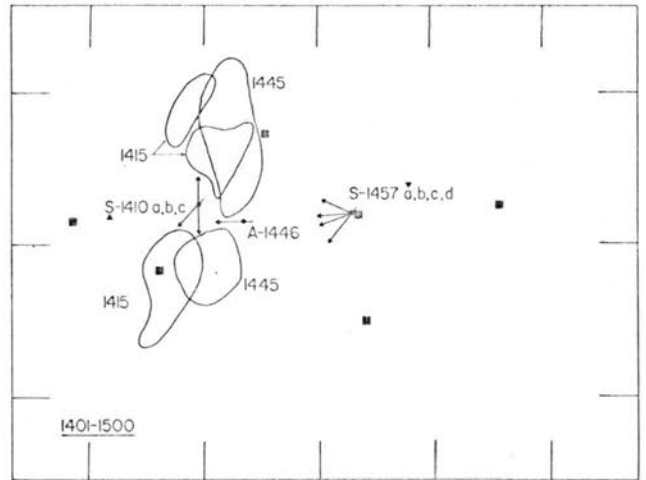
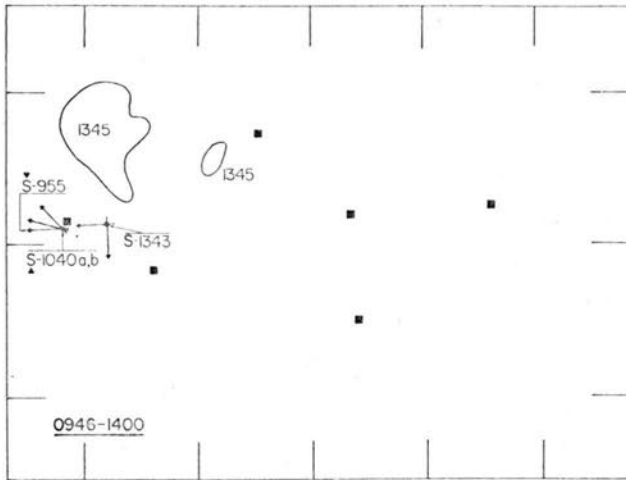


1. Denver, 0500 MST.

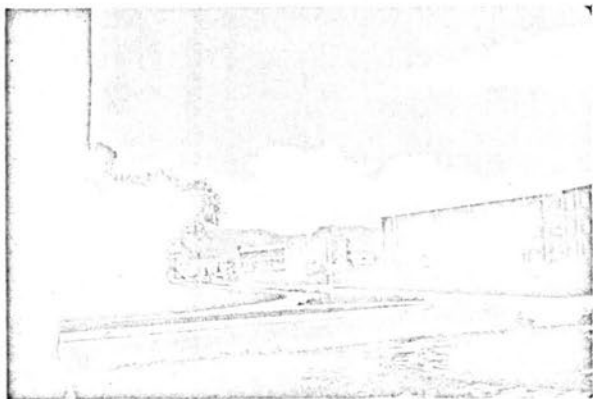


2. Denver, 1700 MST.

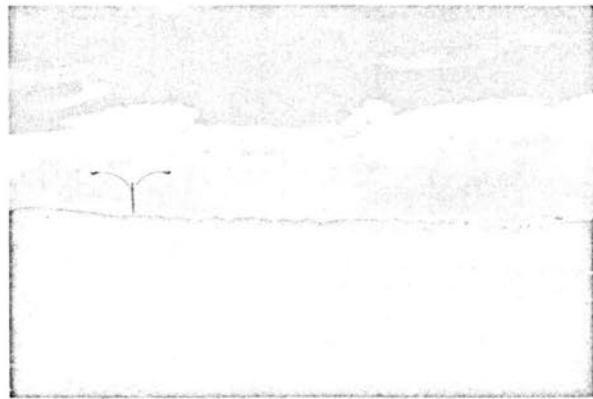
Figure H



13 June 1964
Selected Photos



S-0955 Squall line developing over mountains, west from Colorado State University campus.



S-1040b Squall line developing over the mountains, looking northwest from Colorado State University campus.



S-1410a Looking south from east of Ault at developing squall line.



S-1410b Looking southwest from east of Ault at approaching squall line.

13 June 1964
Selected Photos



S-1410c Looking north from east of Ault at developing squall line.



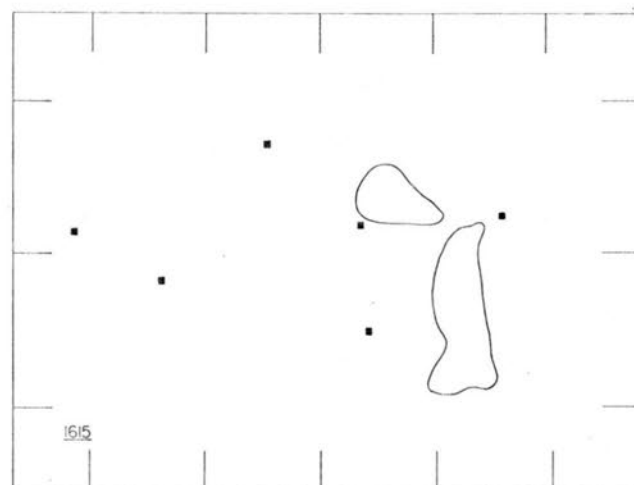
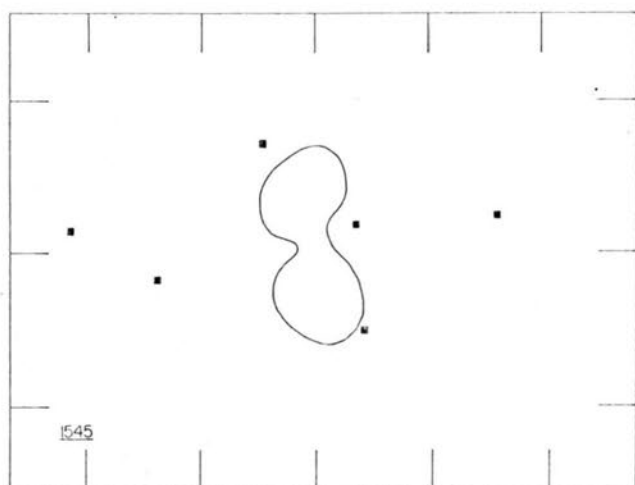
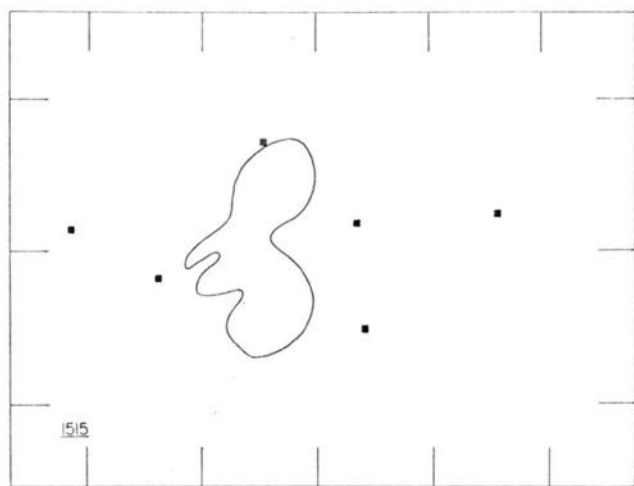
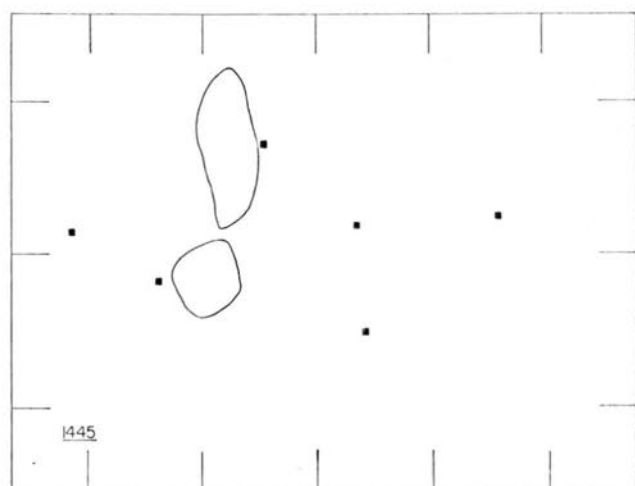
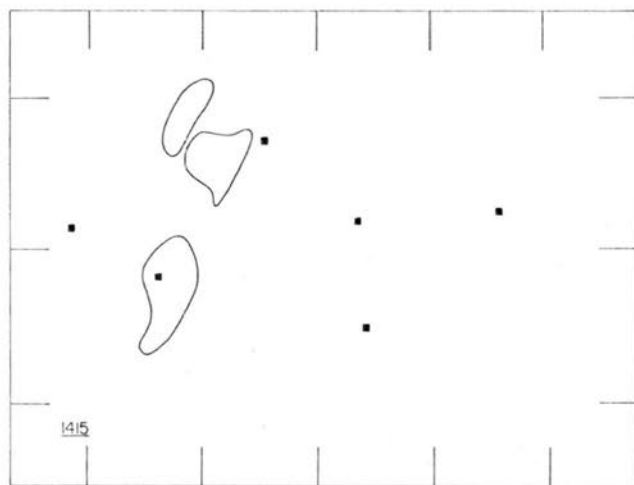
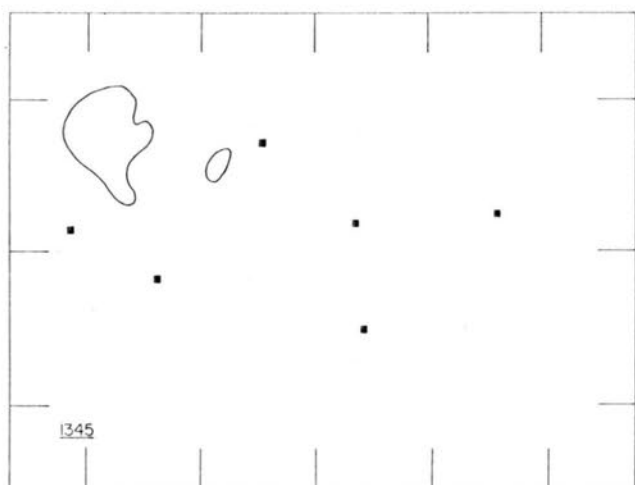
S-1457a Looking southwest from New Raymer at approaching squall line sixteen minutes after test case began.



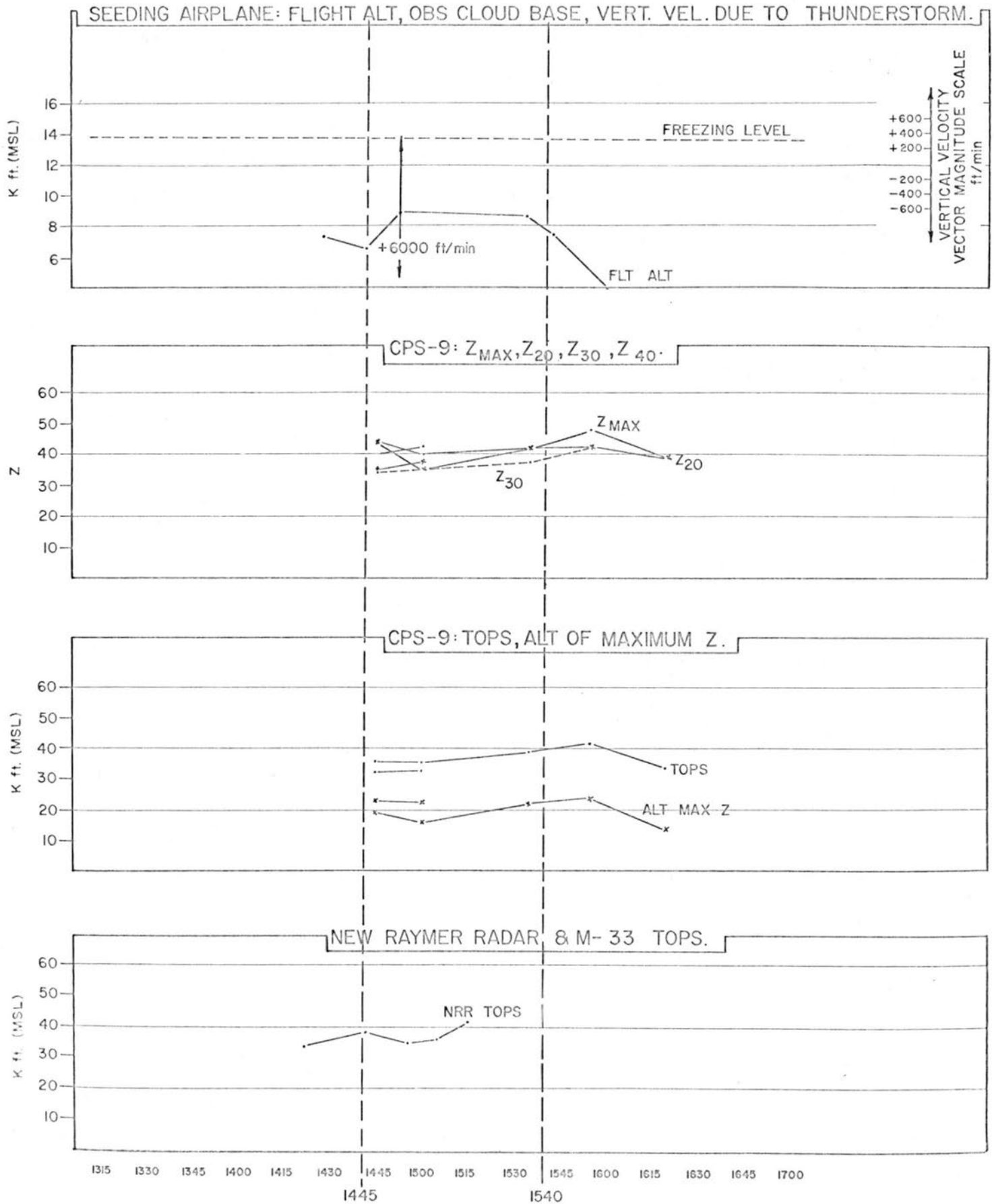
S-1517a Looking south from New Raymer at approaching squall line thirty-six minutes after test case began.

13 June 1964
Radar Echo Positions

Figure I



13 JUNE - 1964
FIGURE J



TEST CASE OF 30 JUNE 1964

Test Case Began 1607 MST, Ended 1702 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 14.0 gms/min. Equipment Used: Lohse Generator.

SUMMARY TABLE.

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MST, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	NA	0	NA	0	NA	0
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	400	3	100	5	-200	1

SIGNIFICANT FEATURES

Northeastern Colorado was under the influence of the weak pressure gradient with a stationary front extending west to east through central Colorado. The 500 mb flow was anti-cyclonic, with a weak jet stream extending from Oregon to North Dakota.

A cumulus growth study was conducted on this day so it was not considered as a formal test case. However, data were gathered as if it were a test case and is presented accordingly.

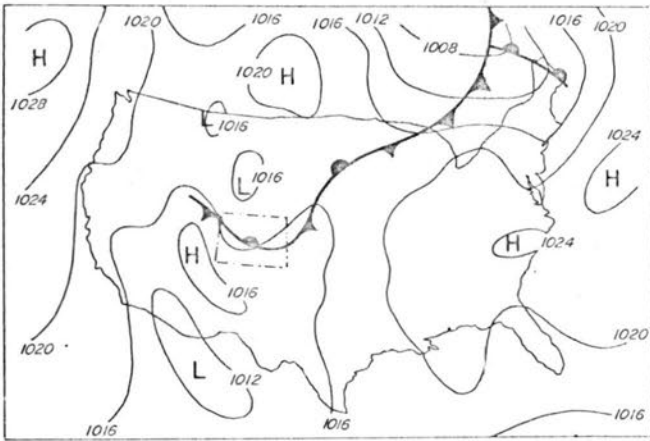
The procedure followed on this particular day differed from the usual test case days in that a small cumulus, which was approximately the same size as a number of others in the immediate area, was chosen for study. The object was to compare the results of a seeded small cumulus to the similar unseeded small cumuli nearby.

Since this was a very small cumulus initially, there was no available radar data. The field data was also limited since there was no ground crew in this area. The visual data, however, is very striking as can be seen from the photos of this cumulus growth study. This particular cell grew very rapidly to the point of producing considerable rain. No other cells in the immediate area did this. Slightly over an hour after seeding began, the study cell began producing moderate, increasing to heavy, local precipitation.

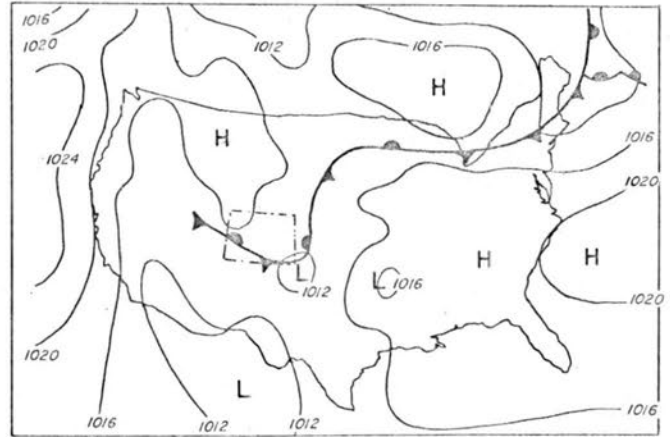
Later in the day a cumulus developed in the vicinity of New Raymer and produced small hail at the radar site. This accounts for no radar data on the study cell in its later stages when it was capable of producing a radar echo since the New Raymer radar does not operate when hail occurs at the site. There was no reported hail from the study cell.

30 June 1964
 U. S. Weather Bureau Synoptic Data

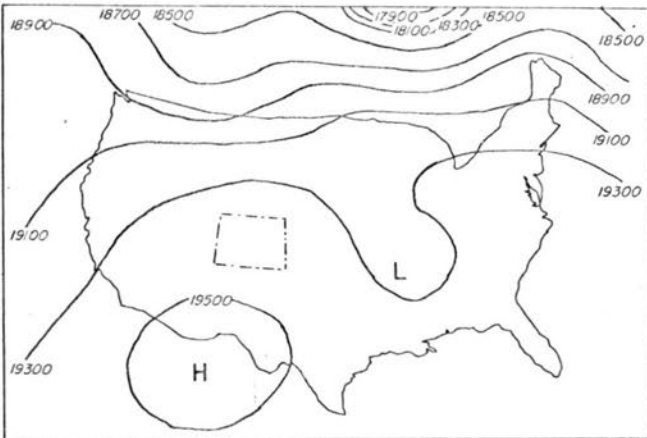
Figures A - F



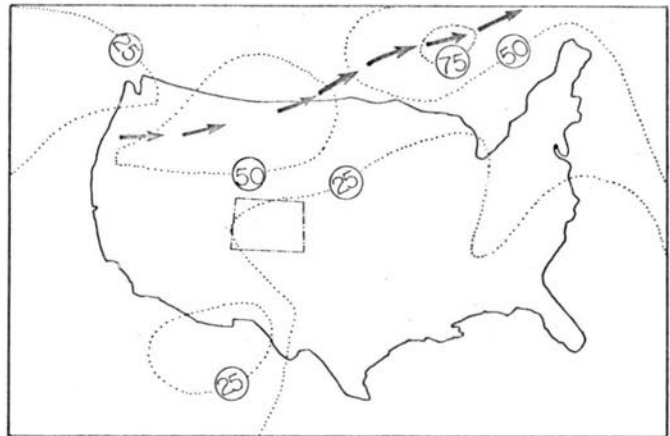
A. Surface Weather Map, 1100 MST (day of test case).



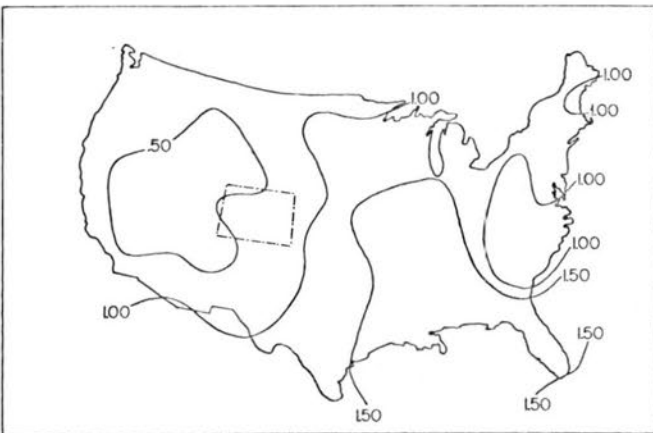
B. Surface Weather Map, 1100 MST (day following test case).



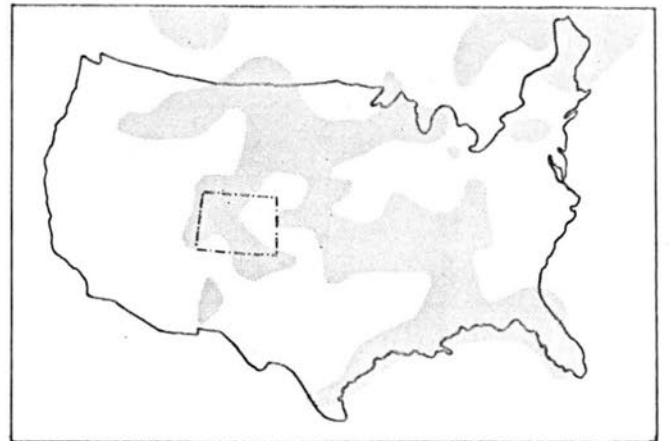
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



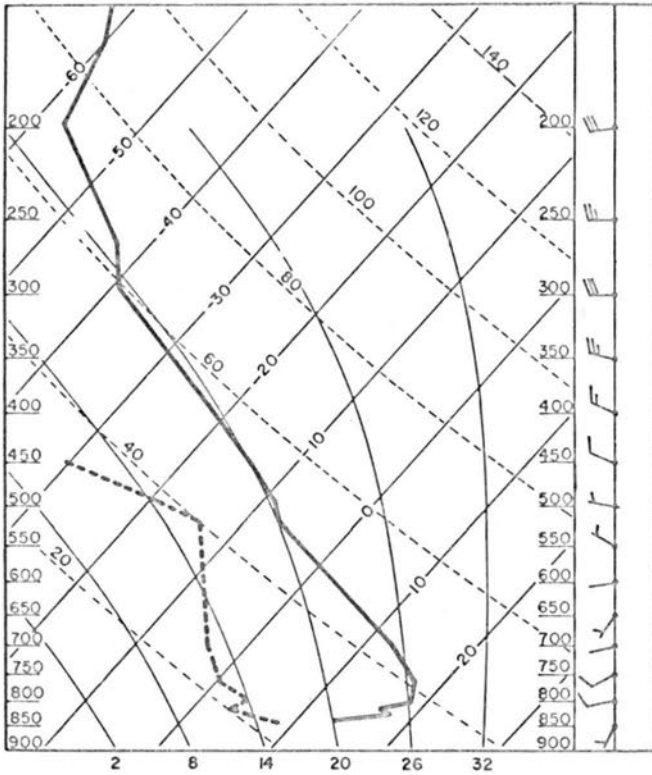
E. Precipitable Water, Inches, 1700 MST.



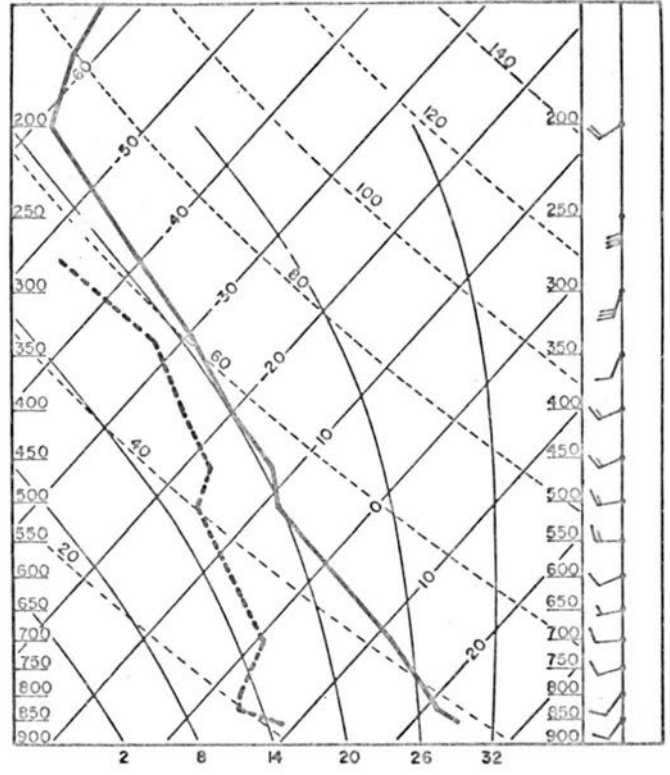
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

30 June 1964
Upper Air Soundings
Skew-T Diagrams

Figure G



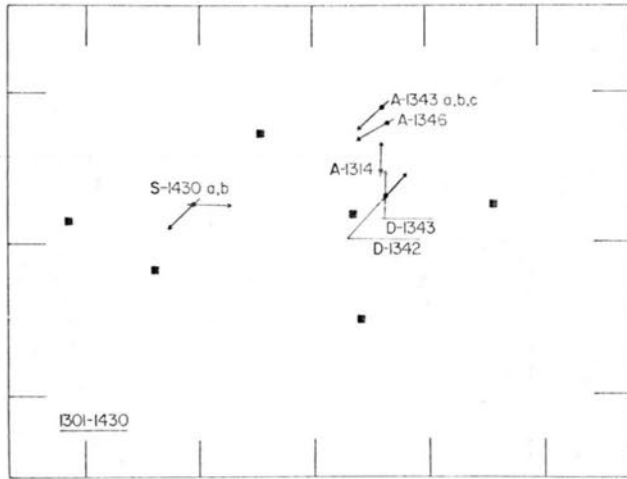
1. Denver, 0500 MST.



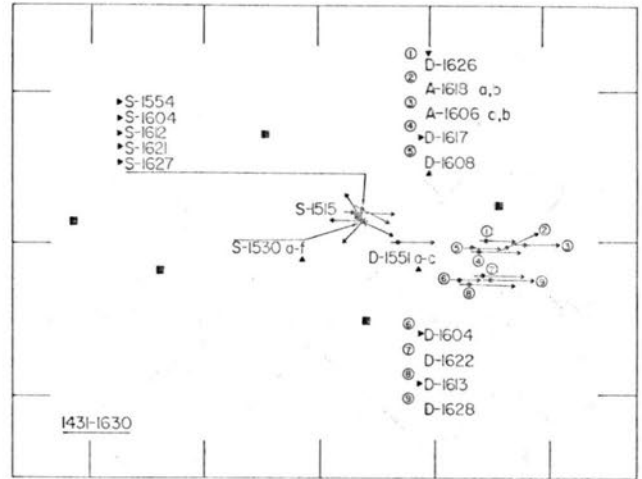
2. Denver, 1700 MST.

30 June 1964
Photo Index

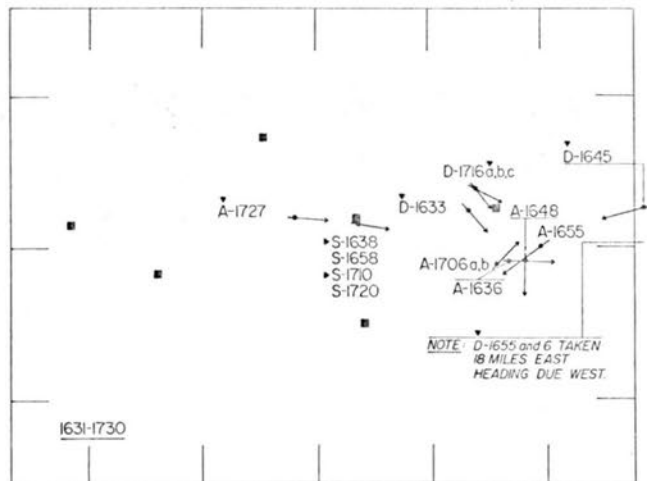
Figure H



1.



2.



3.

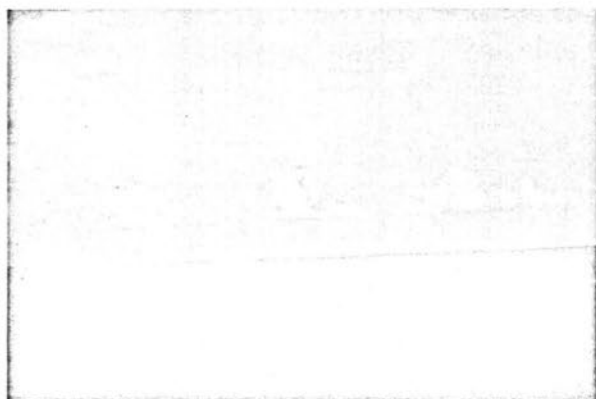
30 June 1964
Selected Photos



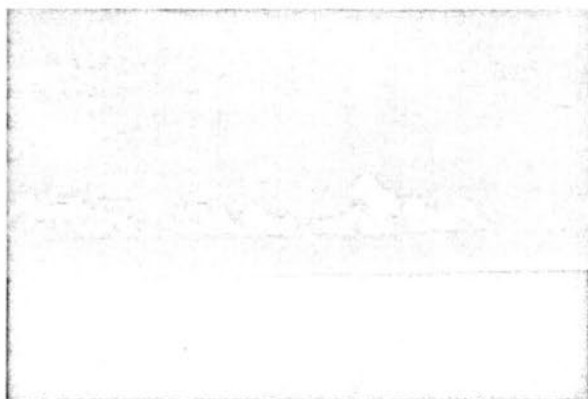
S-1530f Thirty-five minutes prior to seeding of left cumulus. Seeding airplane departing for test case. Cumulus growth study.



D-1551a Sixteen minutes prior to seeding left cell.



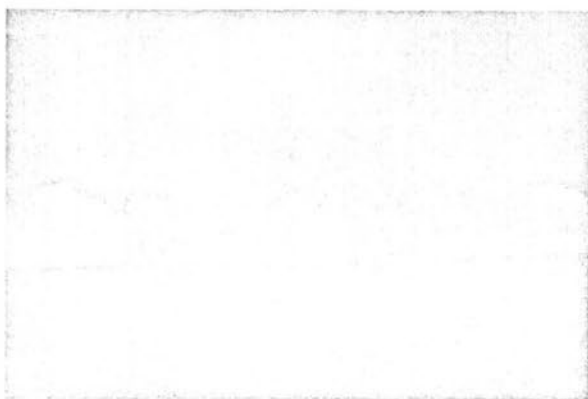
S-1554 Thirteen minutes prior to seeding left cell.



S-1604 Three minutes prior to seeding cell on the right.



D-1604 Three minutes prior to seeding this cell. Most cells in the area remained about this size.

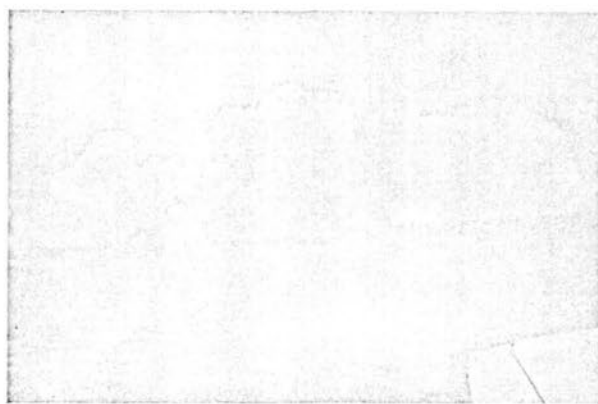


D-1608 Test cell one minute after seeding began.

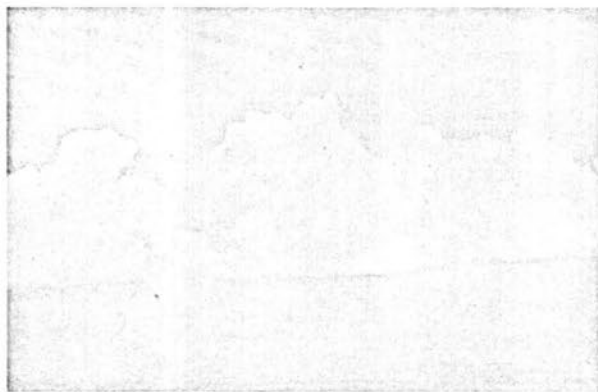
30 June 1964
Selected Photos



S-1612 Five minutes after seeding began on second cell from the right.



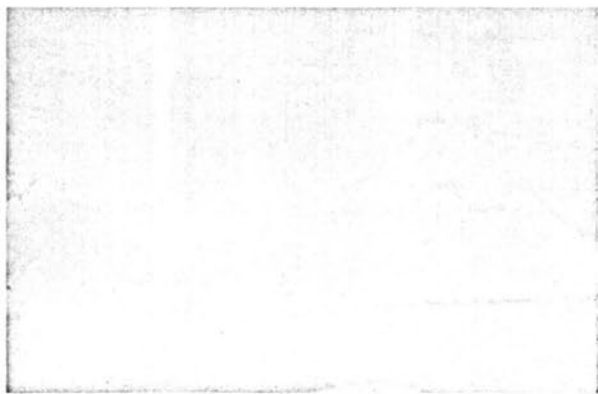
D-1613 Six minutes after seeding began.



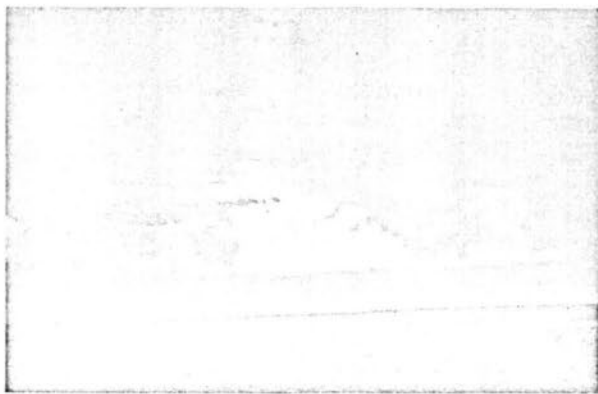
D-1617 Ten minutes after seeding began, taken from about ten miles west of the test cell.



S-1621 Fourteen minutes after seeding began on cell to the right of center.

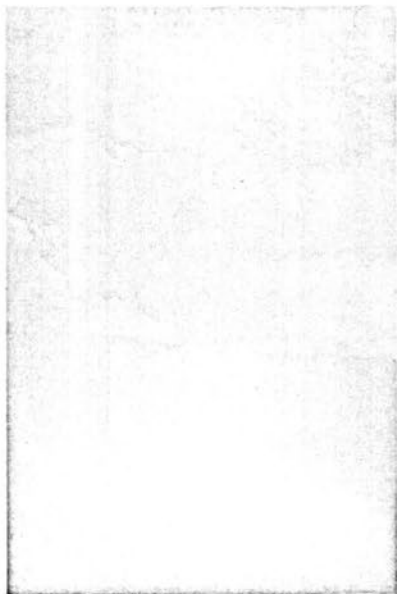


D-1626 Nineteen minutes after seeding began from about ten miles west of test cell.



S-1627 Twenty minutes after seeding began. Note extensive growth in the last fifteen minutes.

30 June 1964
Selected Photos



D-1633 Twenty-six minutes after seeding began from about fifteen miles northwest of test cell.



S-1638 Thirty-one minutes after seeding began.



D-1645 Looking west from the east side of the test cell thirty-eight minutes after seeding began; precipitation beginning.



D-1655 Looking west forty-eight minutes after seeding began; precipitation increasing.

30 June 1964
Selected Photos



S-1710 Sixty-three minutes after seeding began, moderate precipitation reaching the ground.



D-1716a Sixty-nine minutes after seeding began, fairly heavy precipitation reaching the ground.



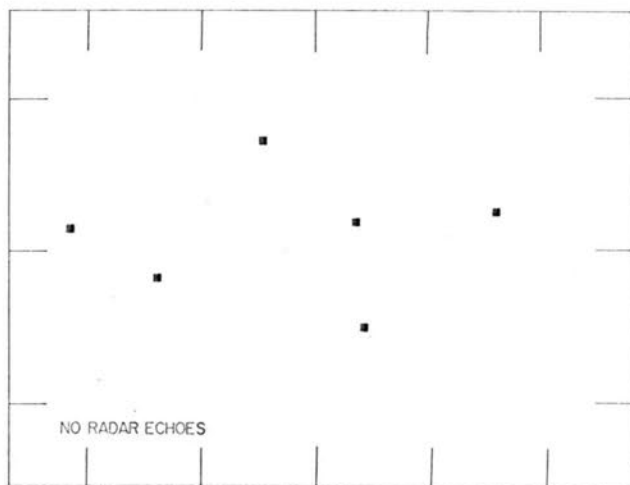
S-1720 Seventy-three minutes after seeding began, twenty minutes after seeding ended, heavy precipitation reaching the ground.



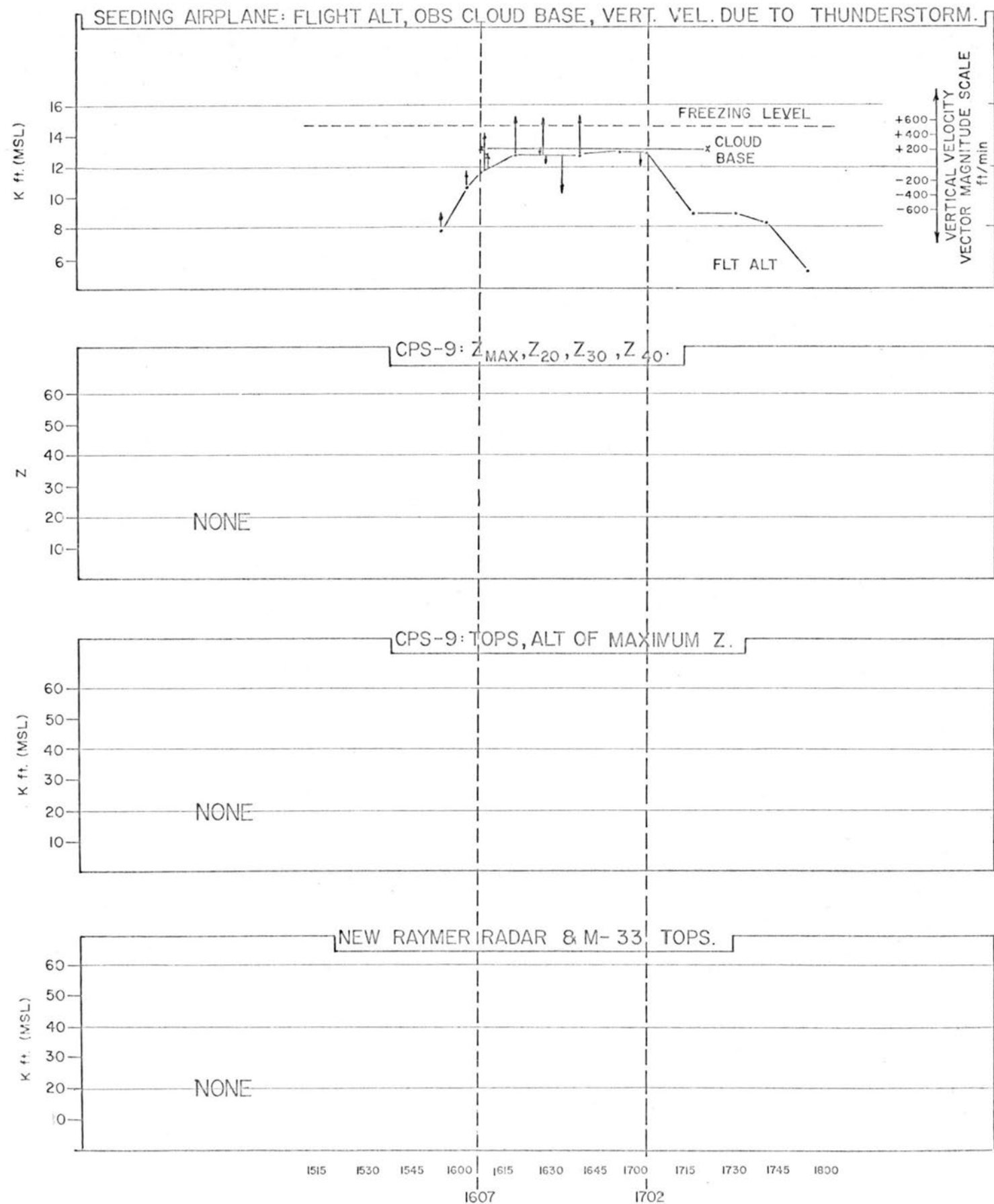
A-1727 A small cumulus that developed near New Raymer and produced light hail.

30 June 1964
Radar Echo Positions

Figure I



1.



TEST CASE OF 6 JULY 1964

Test Case Began 1659 MST, Ended 1830 MST
 Seeded: NO Material Used: None
 Rate of Seeding: None Equipment Used: None

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	3/4	1	1/2	1	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	50,250	4	45,909	11	39,200	5
Radar tops K-ft MSL, CPS-9	48,000	1	33,500	2	NA	0
Radar tops K-ft MSL, NRR	32,000	1	32,333	3	23,750	2
CPS-9 radar reflectivity, Z ₃₀	39	1	40	1	NA	0
Area covered by radar echo, mi ²	90	1	49	1	30	1
Rainfall-volume, acre-feet	3.9		NA	0	NA	0
Maximum updraft, ft/min.	700	2	300	4	200	1

SIGNIFICANT FEATURES

The surface weather map shows a weak frontal system extending east-west through central Colorado with a small low pressure wave in eastern Colorado. Flow at 500 mb was light from the west with the jet stream extending from the southwestern United States into the northern Great Lakes.

All equipment was functioning very well during this test case, and we had an observation airplane for the first time for taking photographs of the test case.

All radar systems were functioning satisfactorily during this test case. The radar tops and reflectivity decreased during the test case, and it was felt that this cell was in the dissipating stages when the test case was initiated.

This test case was a well documented and photographed case since it was in a good location and did not have a large number of clouds obscuring

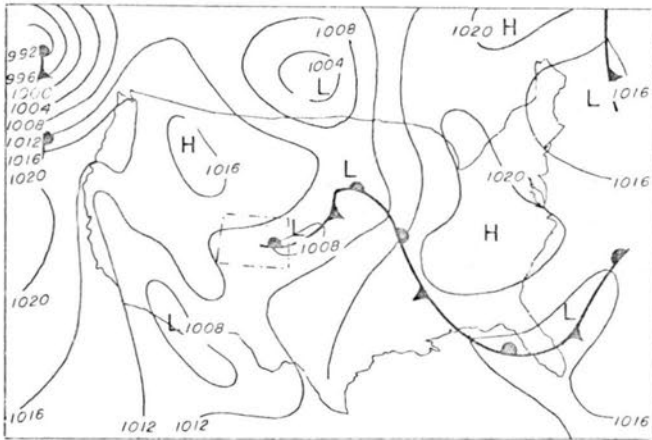
it. The small amount of icing in the middle portion of the cloud and the rapid decrease in the cloud tops led some observers to believe we had seeded the cloud since the other clouds in the area remained as large active cells.

Vertical velocity under the test cell decreased during the time of the test period. Nine minutes before the test case began and nine minutes after it began, 1/4 to 1/2 inch hail was encountered in flight by the seeding aircraft. This hail was encountered in clear air approximately one mile east of the edge of the cloud and under a cirrus overhang. The hail appeared to have been "tossed" out the side of the test cell.

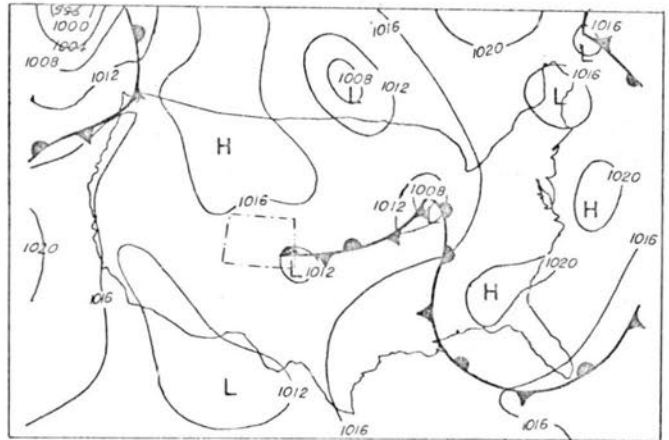
Very little rain fell from the test cell but hail was reported from this cell. Other cells in the area developed and continued to grow into the night producing more rain and quite a lot more hail as illustrated in Figures M and O.

6 July 1964
 U. S. Weather Bureau Synoptic Data

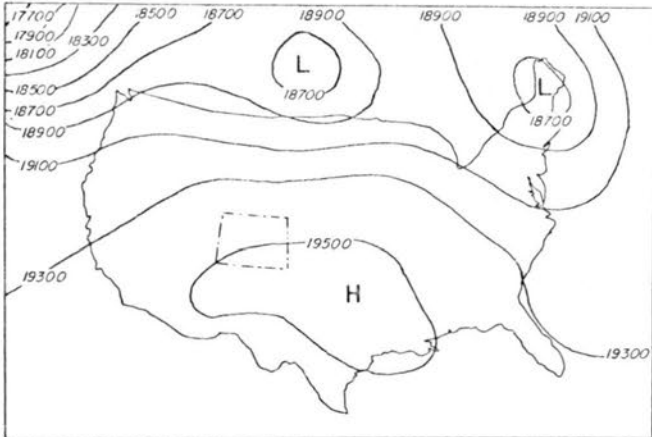
Figures A - F



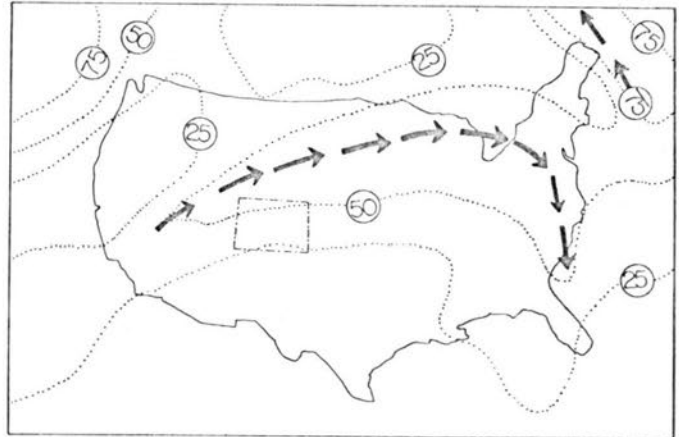
A. Surface Weather Map, 1100 MST (day of test case).



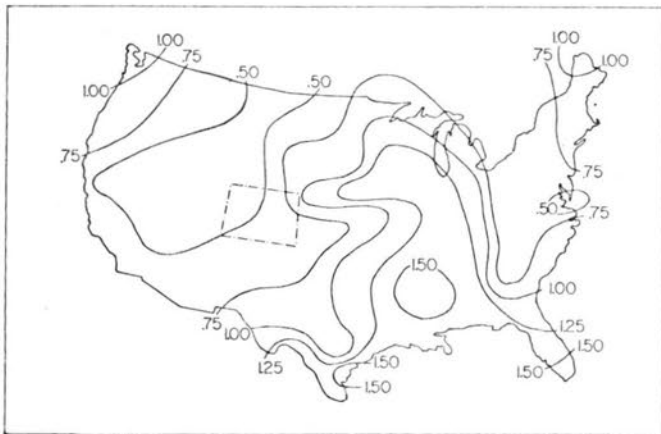
B. Surface Weather Map, 1100 MST (day following test case).



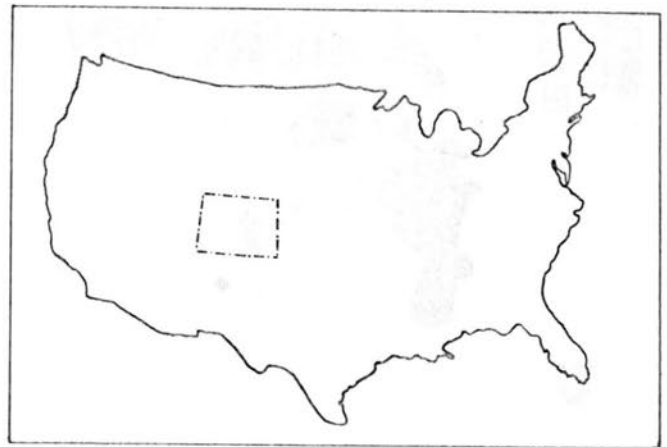
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



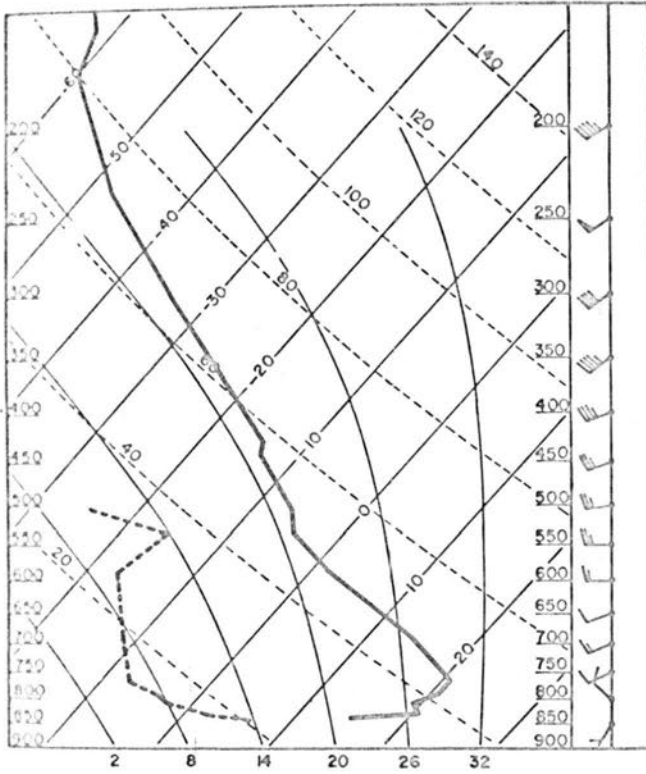
E. Precipitable Water, Inches, 1700 MST.



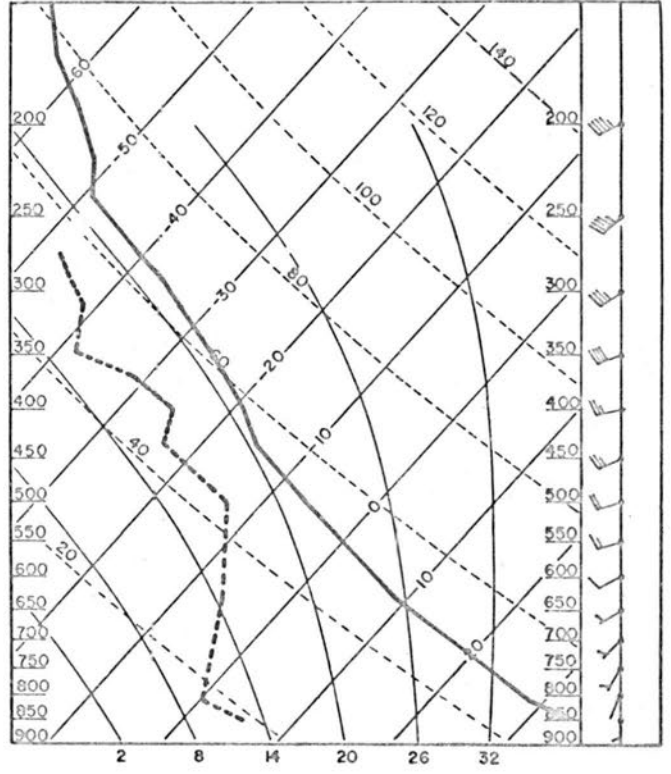
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

6 July 1964
Upper Air Soundings
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Figure G

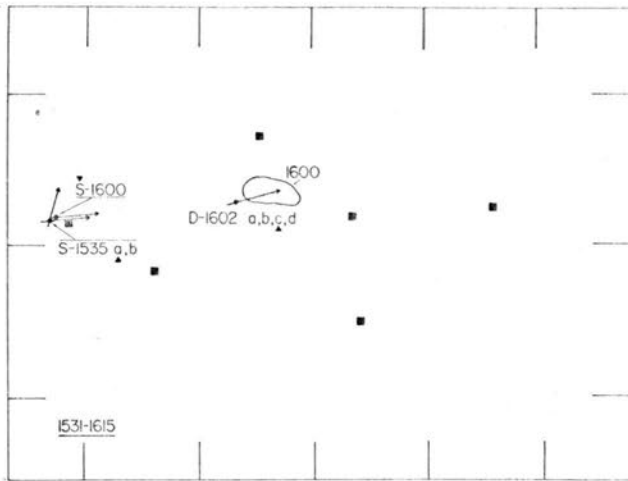


1. Denver, 0500 MST.

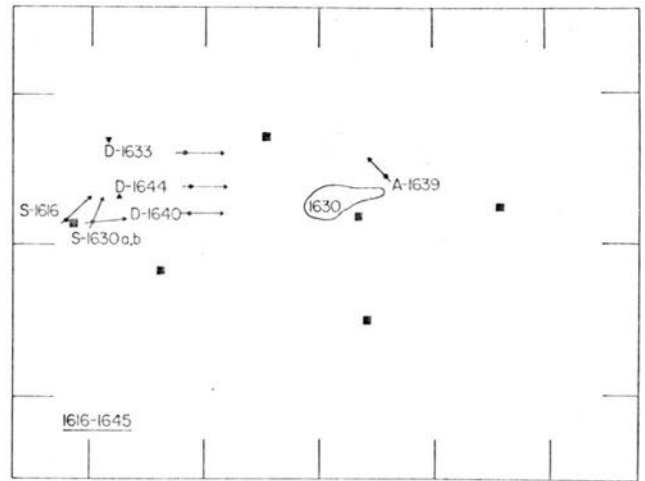


2. Denver, 1700 MST.

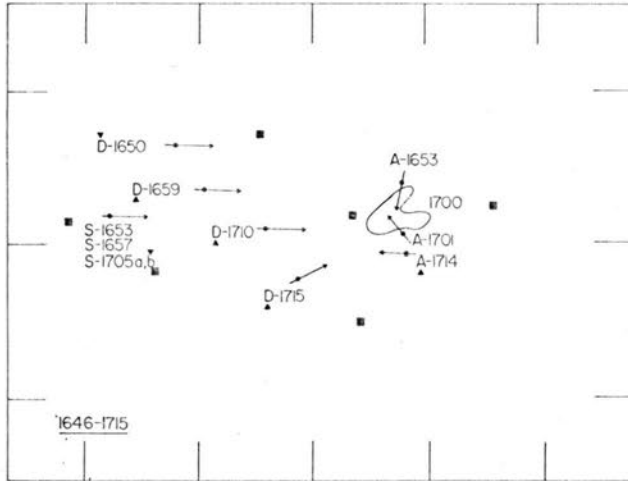
Figure H



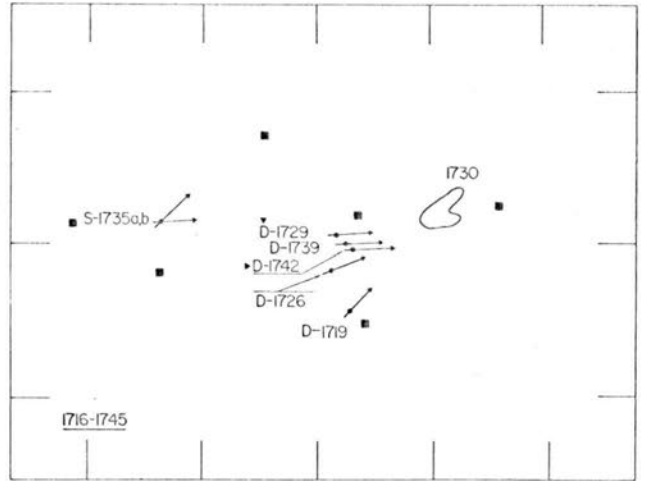
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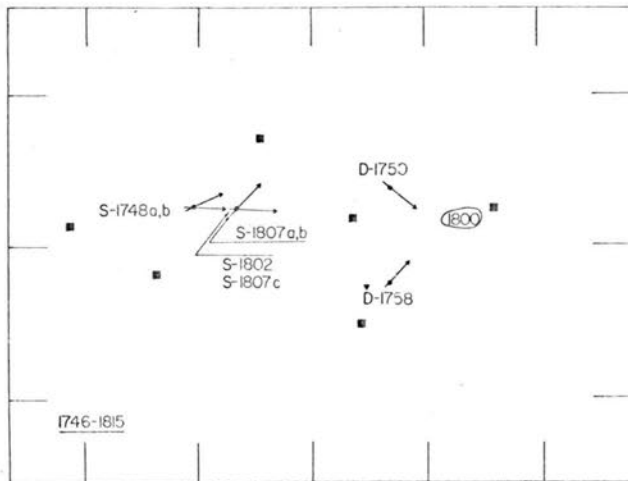
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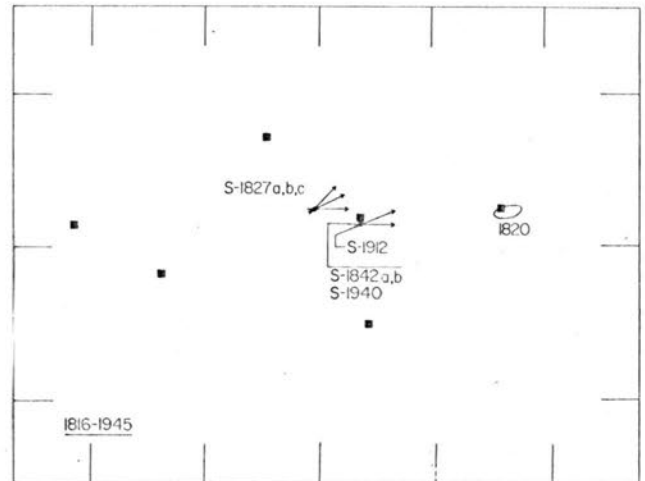
3.



4.

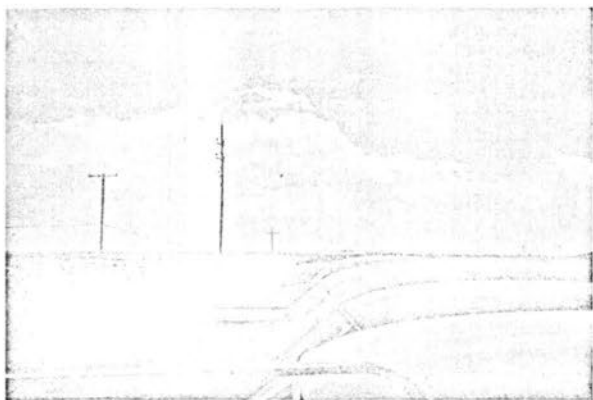


5.



6.

6 July 1964
Selected Photos



S-1535a Towering cumulus developing east of Fort Collins.



S-1600 Same cumulus as in previous picture with continued growth.



D-1602c Looking east, actual test case grew from the south end of this cell.



D-1633 General view of test cell twenty-three minutes prior to beginning of operation.

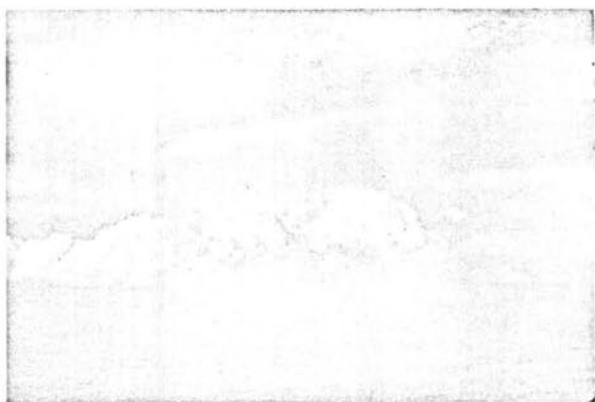
6 July 1964
Selected Photos



D-1644 General view of test cell. Note rapid growth.



D-1650 Nine minutes prior to beginning of test case. Cirrus shield is close to camera obscuring top of test case.



D-1659 Beginning time of the test case operation.



S-1705b Test case from the M-33 site.



D-1710 Fully developed test case cell. Hail was observed from the seeding airplane during the preceding twenty minutes.

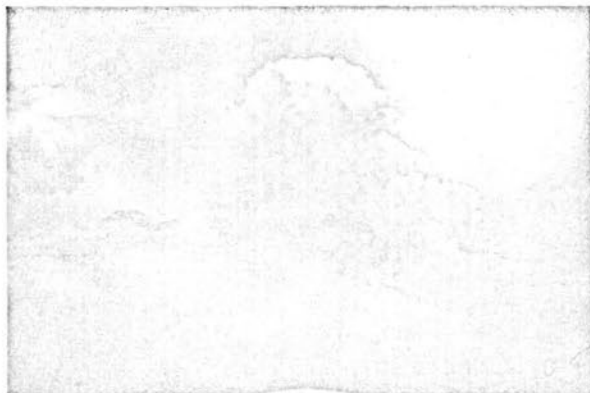


A-1714 South edge of the test case as observed from the seeding airplane.

6 July 1964
Selected Photos



D-1715 Fully developed test case cell.



D-1729 Test case beginning to dissipate.



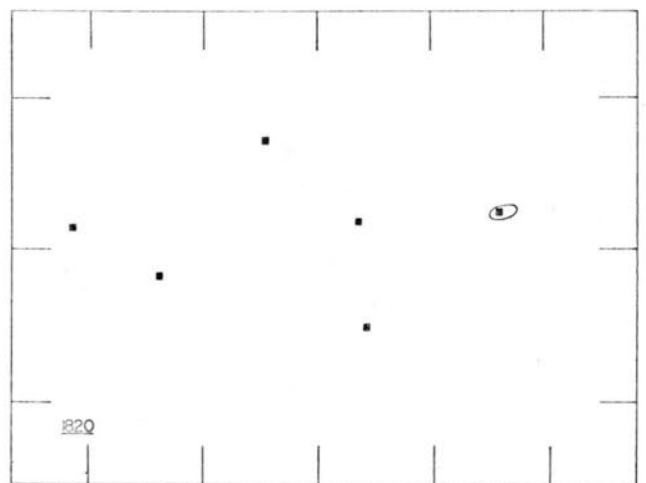
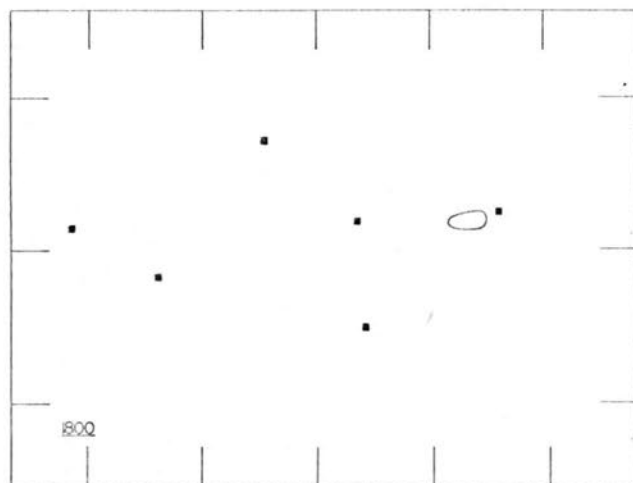
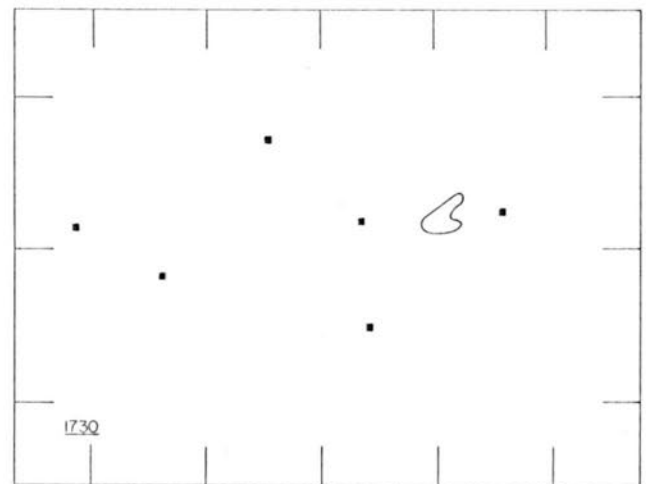
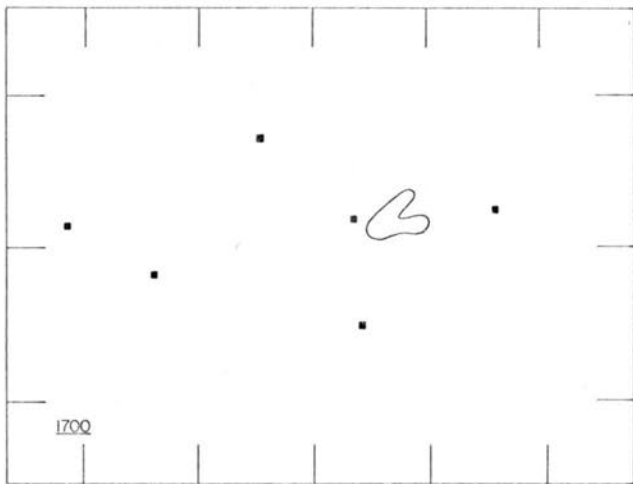
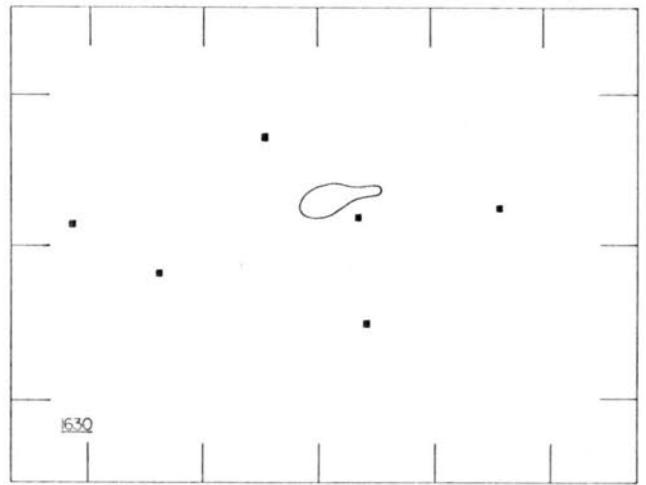
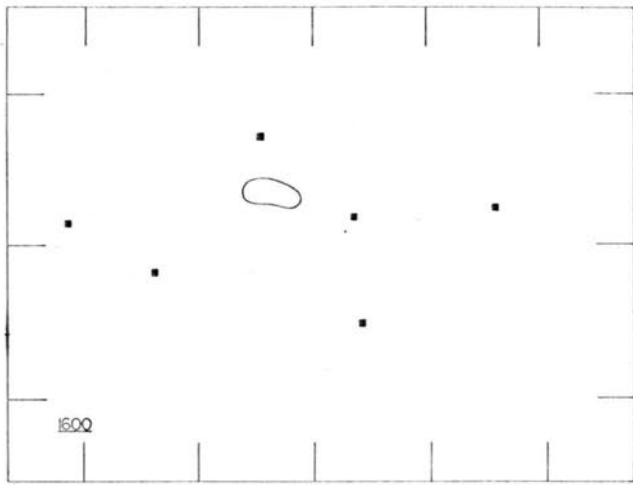
D-1742 Test case dissipating rapidly.



D-1758 Test case almost completely dissipated. This cell was not seeded.

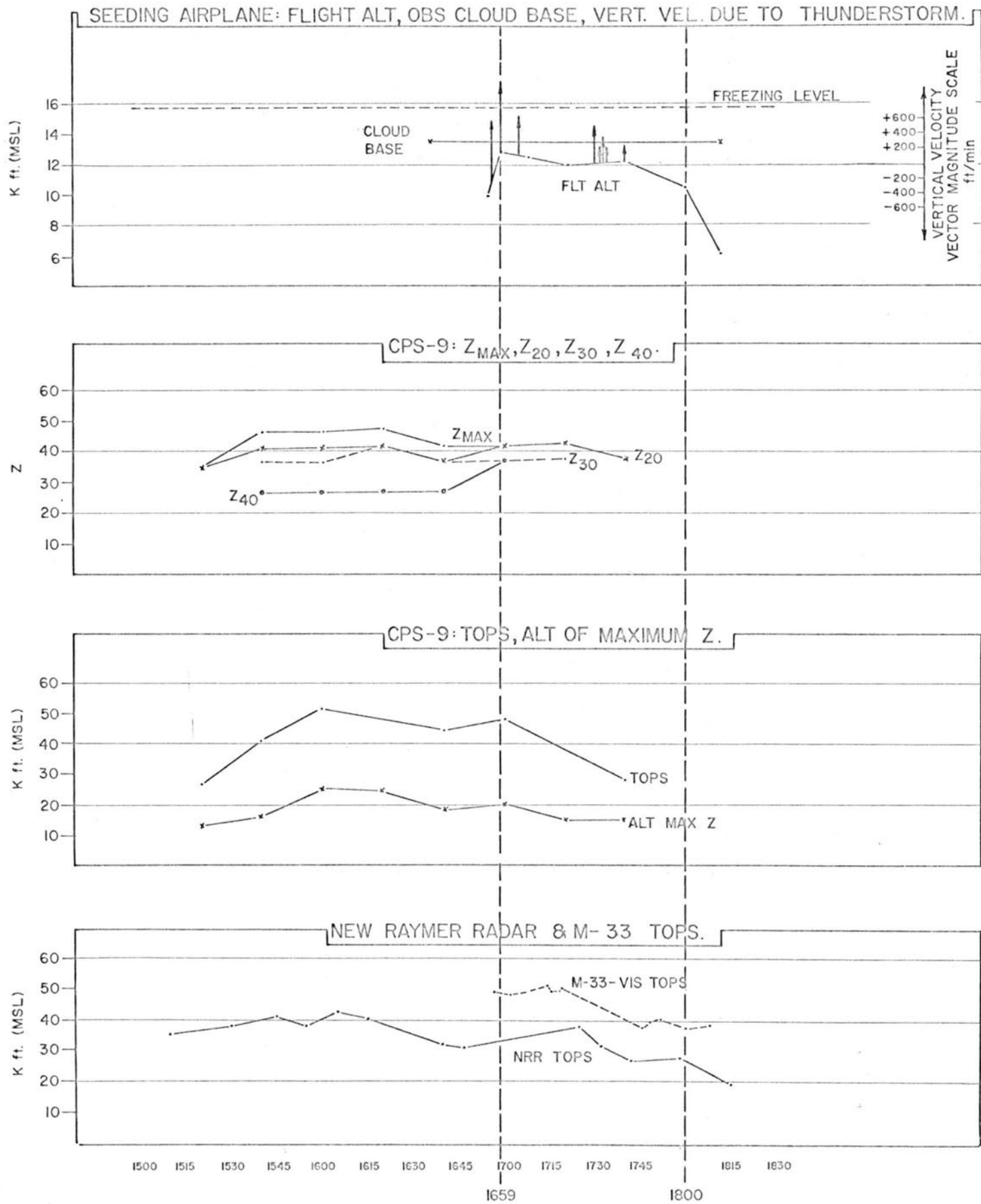
6 July 1964
Radar Echo Positions

Figure I



6 JULY-1964

FIGURE J



TEST CASE OF 7 JULY 1964

Test Case Began 1648 MST, Ended 1807 MST
 Seeded: NO Material Used: None
 Rate of Seeding: None Equipment Used: None

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1 3/4	1	1/2	1	1/2	1
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	54,667	6	64,167	6	49,000	1
Radar tops K-ft MSL, CPS-9	47,500	2	47,000	2	37,500	2
Radar tops K-ft MSL, NRR	43,000	3	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	41.5	2	40	2	28.5	2
Area covered by radar echo, mi ²	183	1	331*	2	NA	0
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	873	7	288.5	8	900	3
*Attenuation						

SIGNIFICANT FEATURES

The surface weather map shows a stationary front extending east-west through central Colorado with a weak surface low pressure area on the front. The upperair flow shows a weak pressure gradient over northeastern Colorado, and a jet stream extending from the northern Rockies to the eastern Great Lakes.

All personnel and equipment functioned satisfactorily during this test case. Due to severe winds and hail at the New Raymer radar site, they were forced to cease operations a short time before the completion of the test case. New Raymer radar also had some difficulty obtaining tops measurements because the test cell was nearly overhead.

Since the test cell was not obscured by other clouds in the area, good photo and visual observations were obtained. The photos of the test cell give a very good representation of the immense size of this system. This test cell was a very severe system and its severity was intensified by the fact that it merged with another equally severe storm. This was a very unusual situation in that the test cell was rapidly moving to the northeast and the other cell was moving at about the same rate to the southeast. The two cells merged almost directly over New Raymer resulting in a phenomenal display of cloud growth. The visual tops of this merged system grew to 70,000 feet, as measured by the

M-33 radar. The rapid growth to the west of the merging cells and their new direction of movement to the east produced a spectacular display.

Severe turbulence was experienced by the seeding aircraft beneath the rapidly growing portion of the test cell. The seeding aircraft was caught in the convergence area and experienced extreme updrafts. The confirmed magnitude of these updrafts exceeded 4,500 feet per minute. The updrafts throughout the test case were strong. The updrafts and turbulence in their convergence area were considered to be too severe for safe flight; hence, not feasible for seeding in this region if it had been an actual seed case.

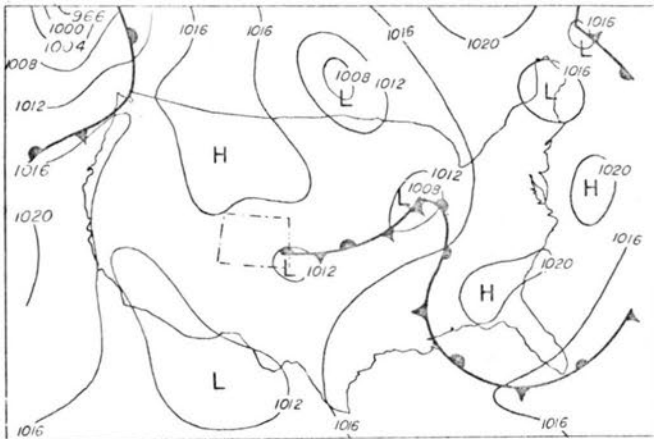
The convergence area produced large hailstones (1/4 to 1 inch in diameter) and covered a large area with these. Some stones were reported to have been baseball size but not.

Although this storm was large and severe, it produced only very localized rains. The area of convergence near New Raymer had a small maximum of precipitation.

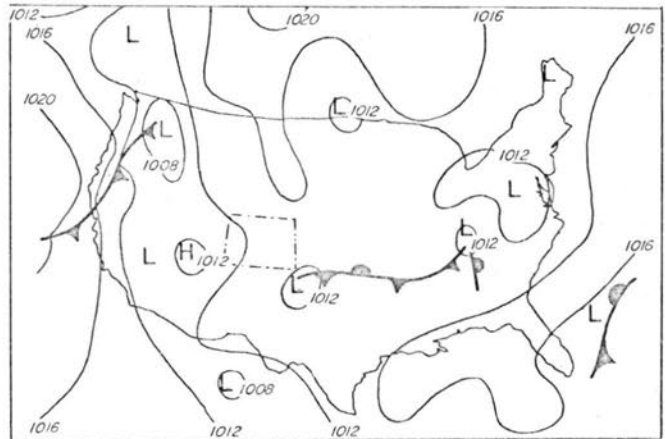
The test case and the cell which converged with it predominated the entire weather picture in northeastern Colorado. There were no other clouds in the area of any consequence.

7 July 1964
U. S. Weather Bureau Synoptic Data

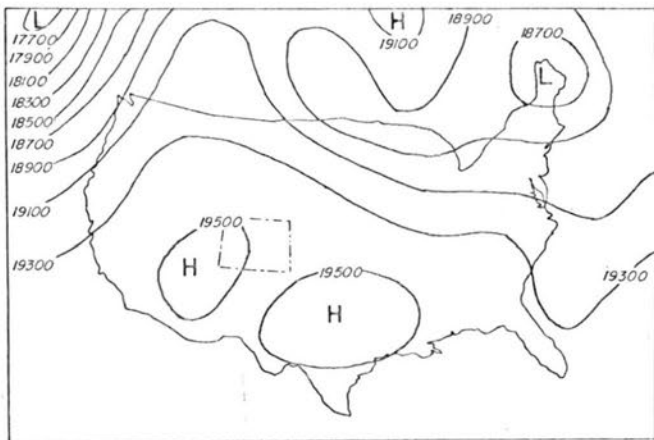
Figures A - F



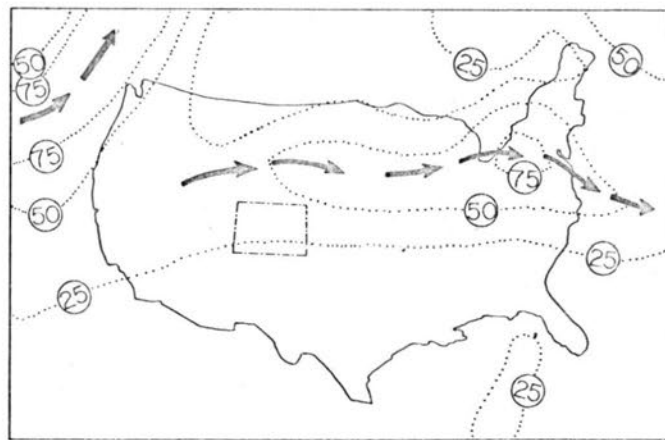
A. Surface Weather Map, 1100 MST (day of test case).



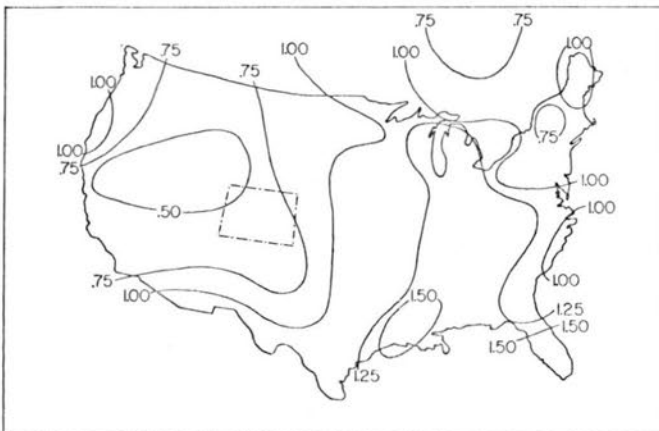
B. Surface Weather Map, 1100 MST (day following test case).



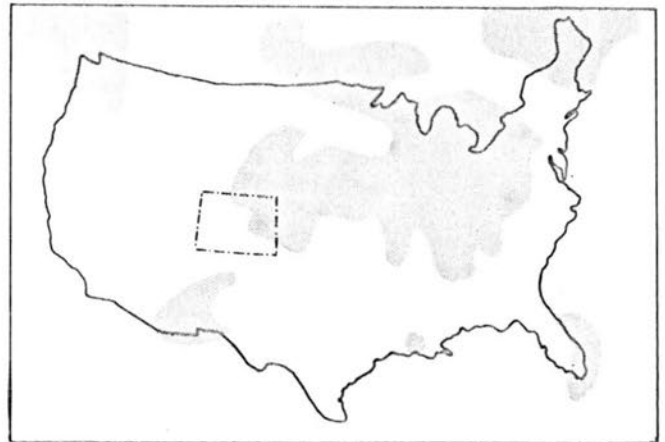
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



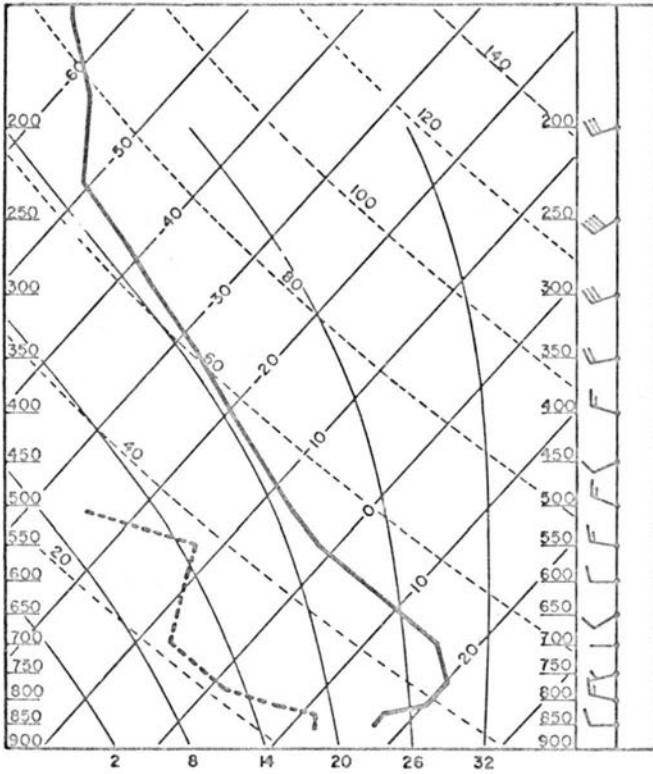
E. Precipitable Water, Inches, 1700 MST.



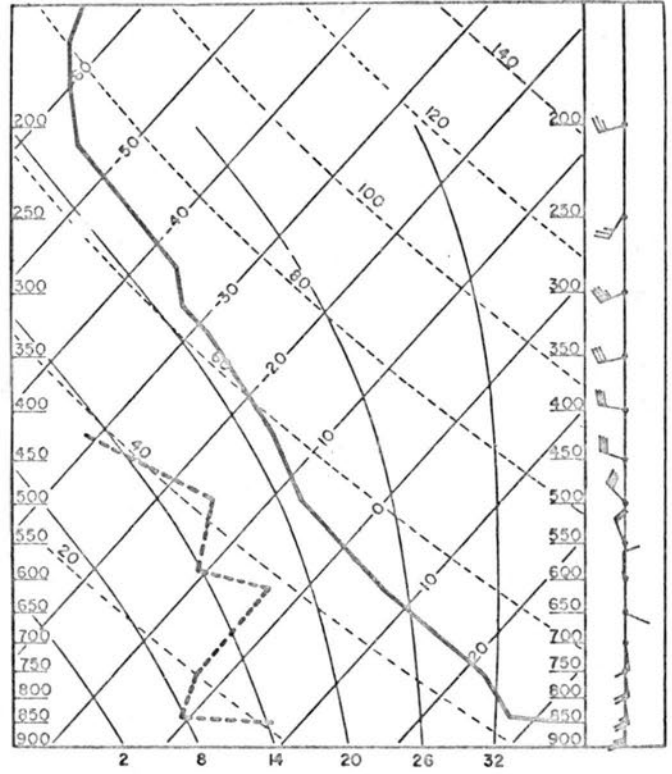
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

7 July 1964
Upper Air Soundings
Skew-T Diagrams

Figure G

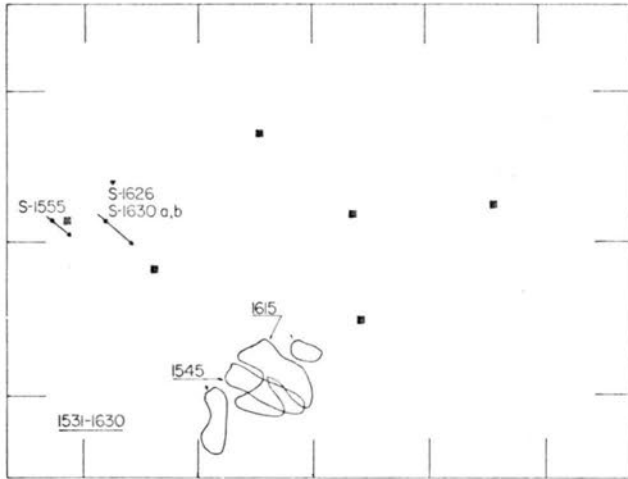


1. Denver, 0500 MST.

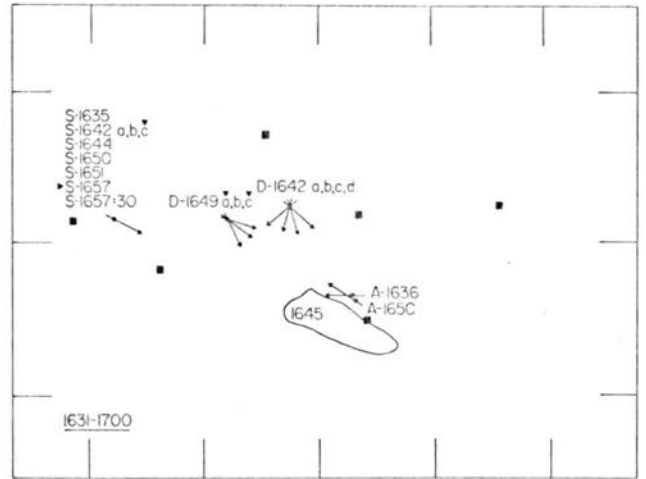


2. Denver, 1700 MST.

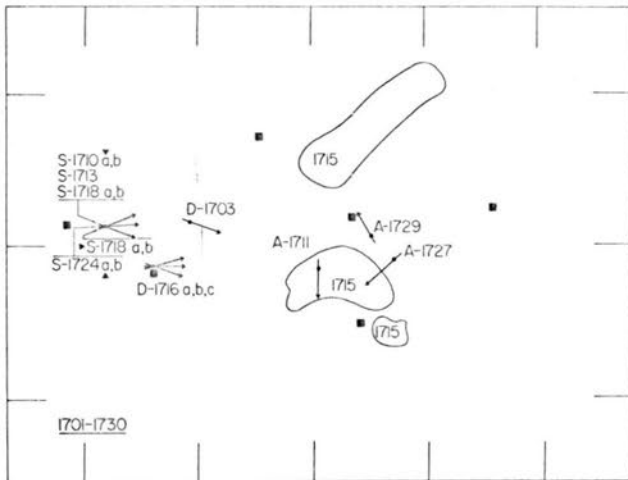
Figure H



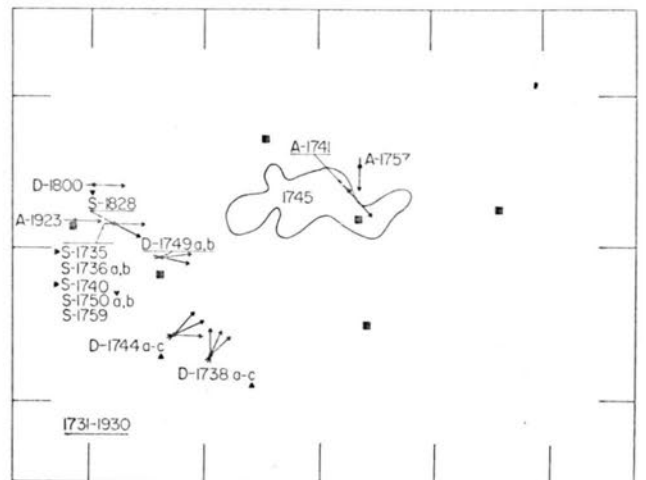
1.



2.



3.



4.

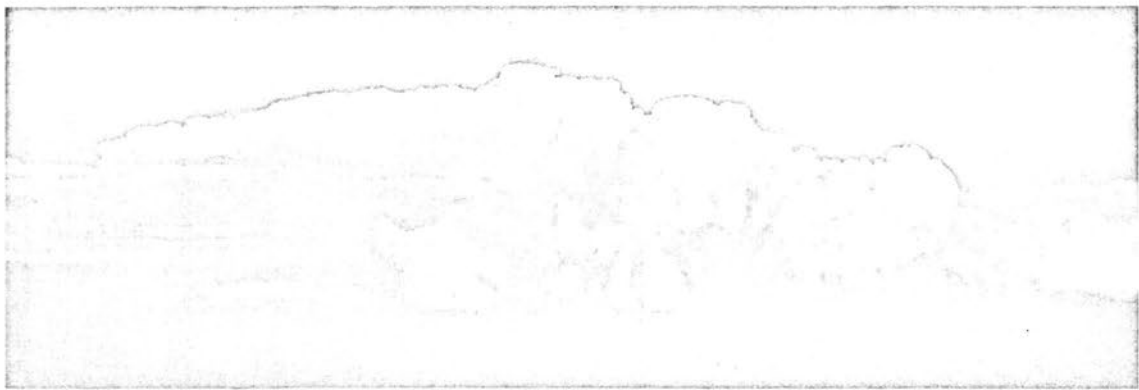
7 July 1964
Selected Photos



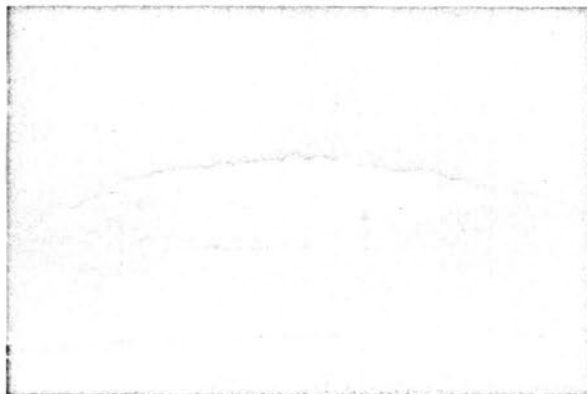
S-1626 Looking southeast from M-33 twenty-two minutes prior to beginning of test case.



D-1642c Looking at the northwest corner of the test case. Note flat bottom, sharp edges and rapid growth.

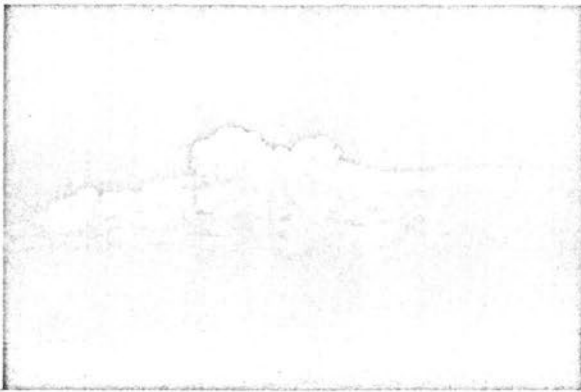


D-1649a,c Panoramic view of entire test case cell. Note the huge size of this system.



S-1657 Telephoto shot of test cell from M-33.

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Selected Photos



S-1710a Telephoto shot from M-33. Note new growth on top of the cell since the previous photo.



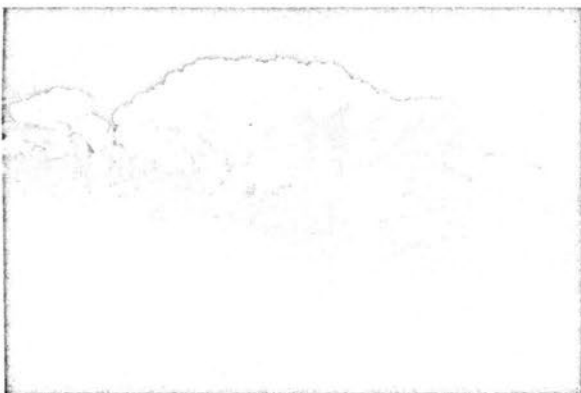
S-1718a Separate cell moving in from the northwest which is beginning to merge with the test cell.



S-1718a,b Test cell moving in from the southwest which is beginning to merge with the cell from the northwest.



S-1724a Looking east from M-33 at merging cells.



S-1735 Telephoto shot of cell growing to west of the merging cells. Severe updrafts encountered at this time.



D-1738c Looking north at the west end of cell growing to the west. Rapid growth to the west from the area of convergence.

7 July 1964
Selected Photos



S-1740 Cell growing to the west as seen from the M-33.



D-1744c Looking to the north at cell growing to the west. Note extensive growth since D-1738c.



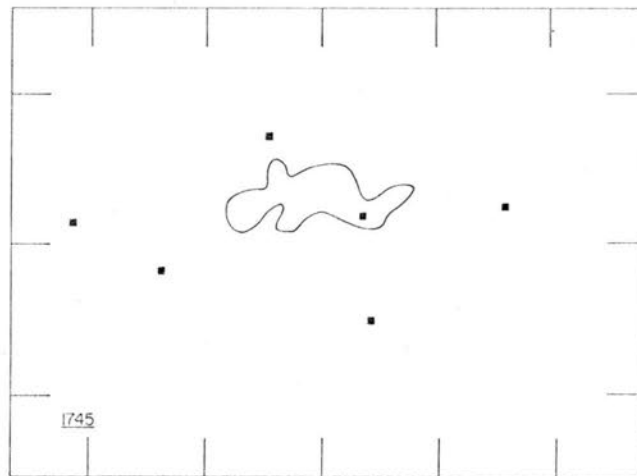
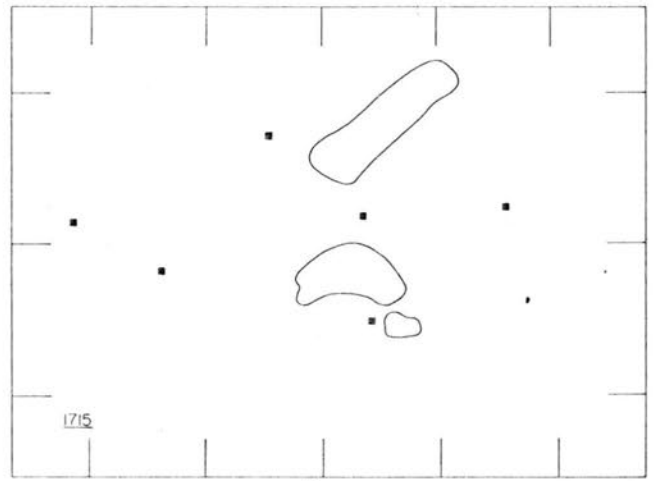
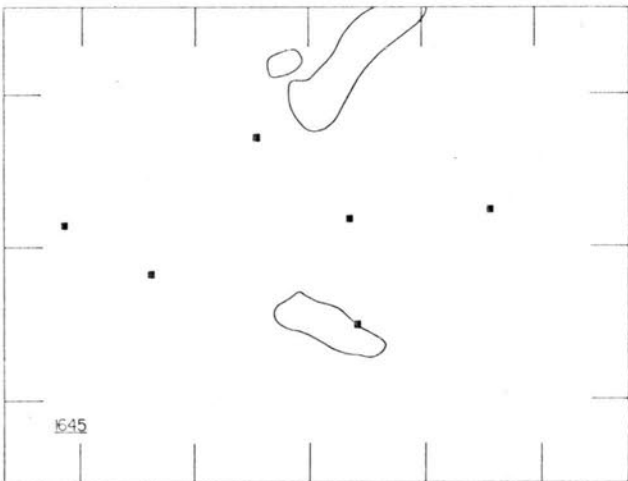
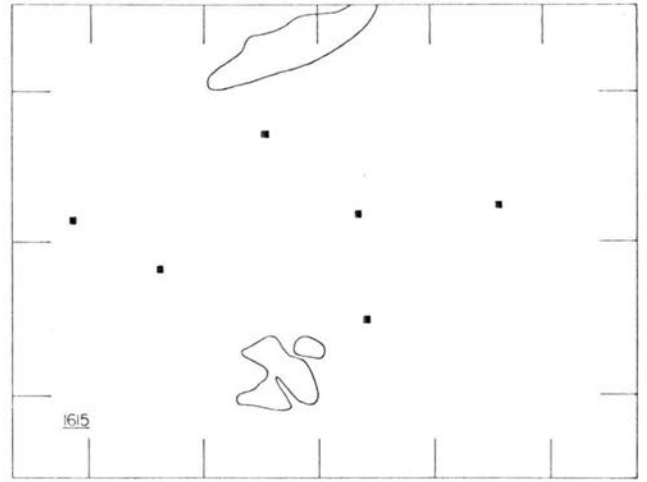
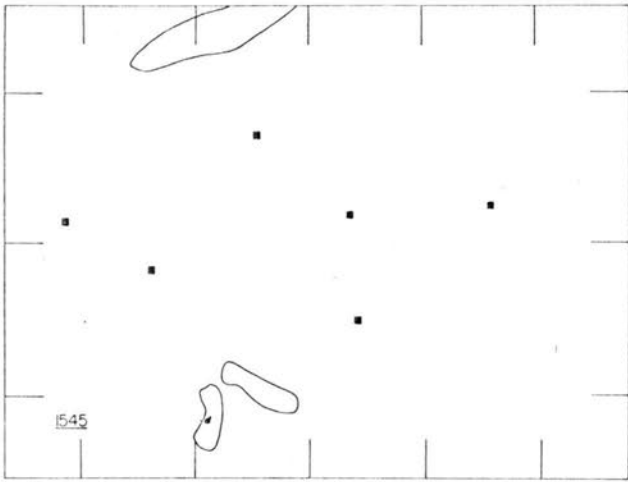
S-1750a Cell from M-33 still growing to the west.



S-1828 Looking southeast from M-33 at rear side of test case area. Merged cells are now moving east.

7 July 1964
Radar Echo Positions

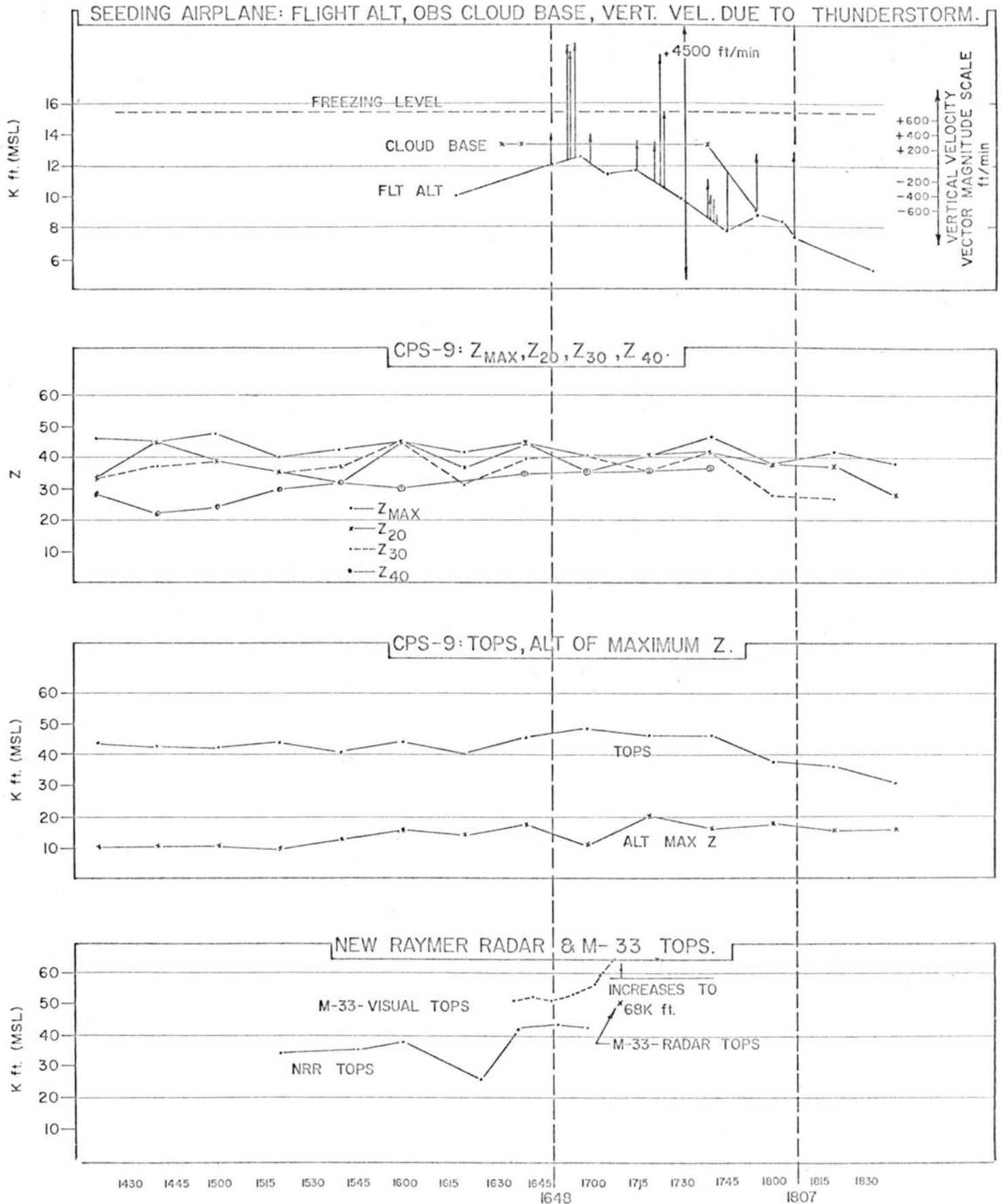
Figure I



5.

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FIGURE J



TEST CASE OF 8 JULY 1964

Test Case Began 1800 MST, Ended 1855 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 14.0 gms/min. Equipment Used: Lohse Generator

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/4	1	1 1/2	1	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	37,000	2	45,500	2	48,000	1
Radar tops K-ft MSL, NRR	39,000	1	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	40	1	43	2	44	1
Area covered by radar echo, mi ²	157	1	21*	1	39*	1
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	1,000	2	800	1	300	1
*Attenuation						

SIGNIFICANT FEATURES

The surface weather map shows a weak pressure gradient over northeastern Colorado with a stationary front and associated pressure wave in extreme southeastern Colorado and the Oklahoma Panhandle. Upper level flow was light from the northwest with a jet stream extended from the western Dakotas to the central Atlantic coast.

The development of cloud formations followed the pattern of changing from clear skies in early morning to developing cumulus by noon and strong thunderstorm activity in the late afternoon. (See selected photos for pictures of cloud development.)

The New Raymer radar had trouble getting good data on this case because the storm passed nearly overhead resulting in lightning and hail at the site, forcing the radar to be shut down. Other than this, all the equipment and personnel were in the field and functioning properly.

Visually this was a very spectacular test case. The observation airplane was positioned during the test case so as to make many visual observations and take many pictures. An interesting observation was made by the seeding aircraft that early in the test case the upair was concentrated around a small

cumulus cloud about 500 feet below the cloud base. These updrafts maintained a 1,500-2,000 feet per minute magnitude for the duration of the small cumulus, about 15 minutes. It was observed by the seeding and observation airplanes that late in the test case there was a very definite "roll cloud" development about 1,000 feet above ground level. Above this "roll cloud" there were very strong updrafts.

Perhaps one of the most significant features of this test case was the fact that it built out of the "left flank" rather than the more commonly observed "right flank" development.

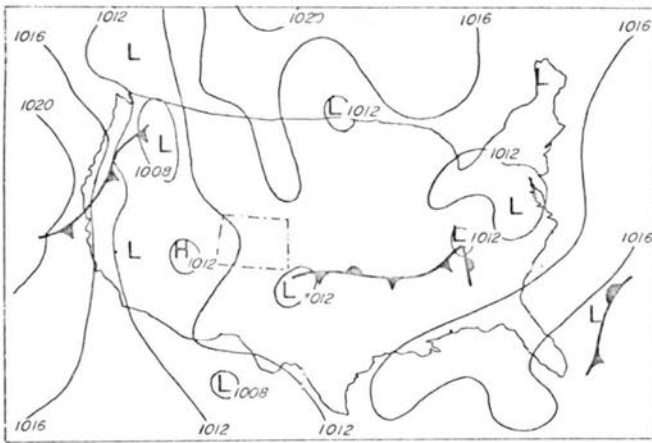
The test case displayed icing in the upper levels of the cloud late in the operation.

The radars observed an increase in the radar tops and an increase in the radar reflectivity throughout the test case.

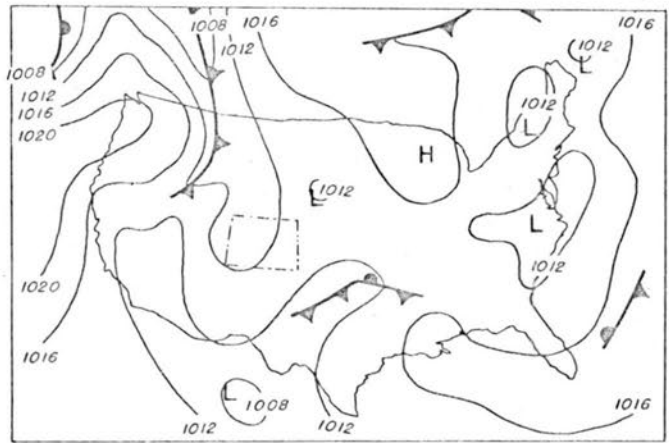
There were a number of cumulus buildups in the area during this test case day and quite a lot of local rain and hail in the area. The test case itself produced a significant amount of rain and hail in the area of operation.

8 July 1964
 U. S. Weather Bureau Synoptic Data

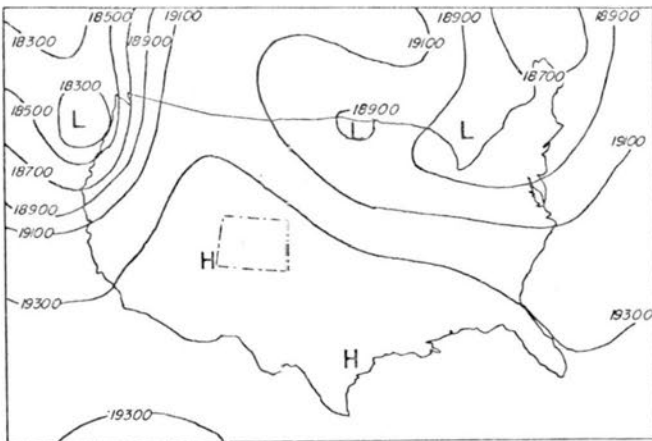
Figures A - F



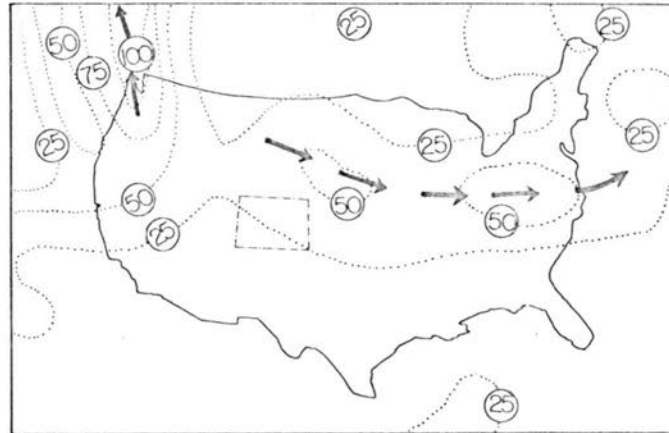
A. Surface Weather Map, 1100 MST (day of test case).



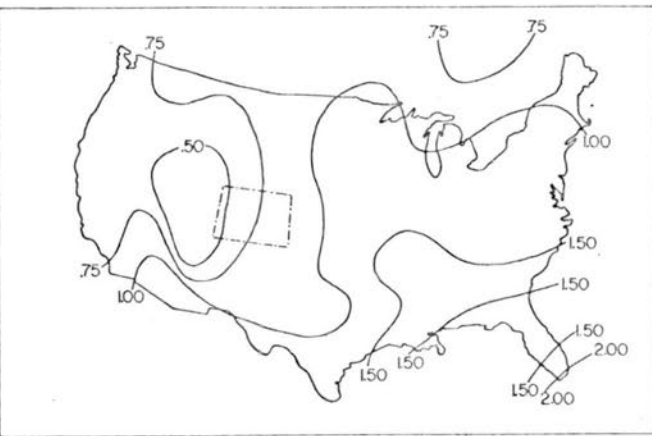
B. Surface Weather Map, 1100 MST (day following test case).



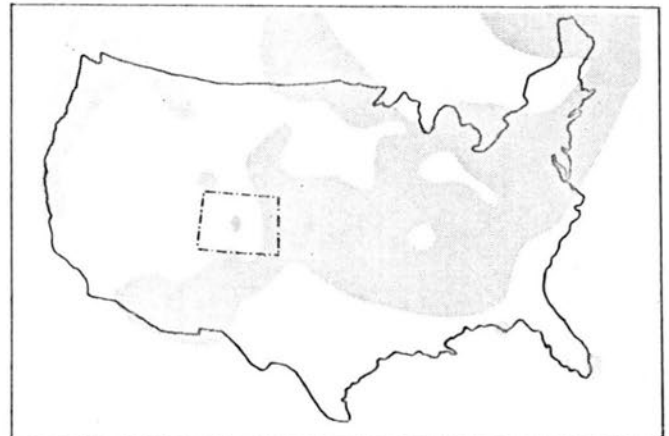
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



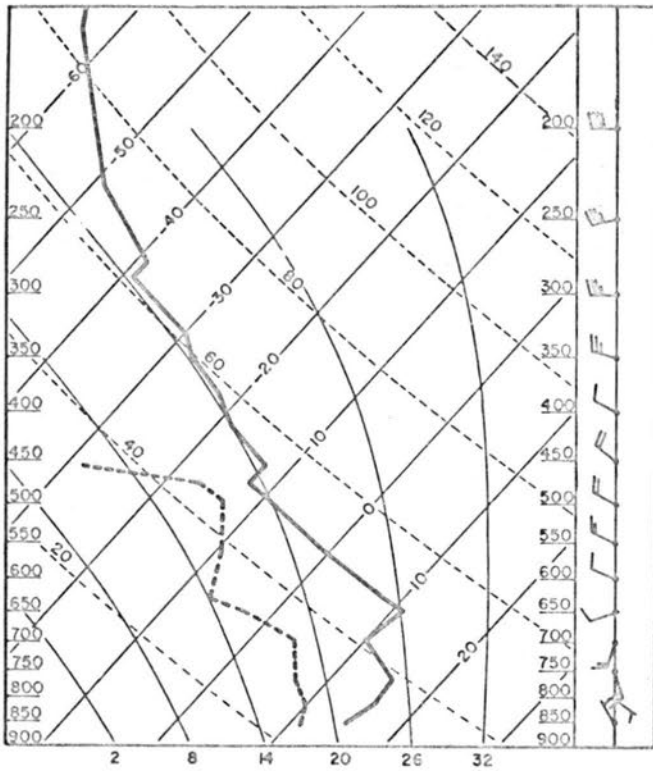
E. Precipitable Water, Inches, 1700 MST.



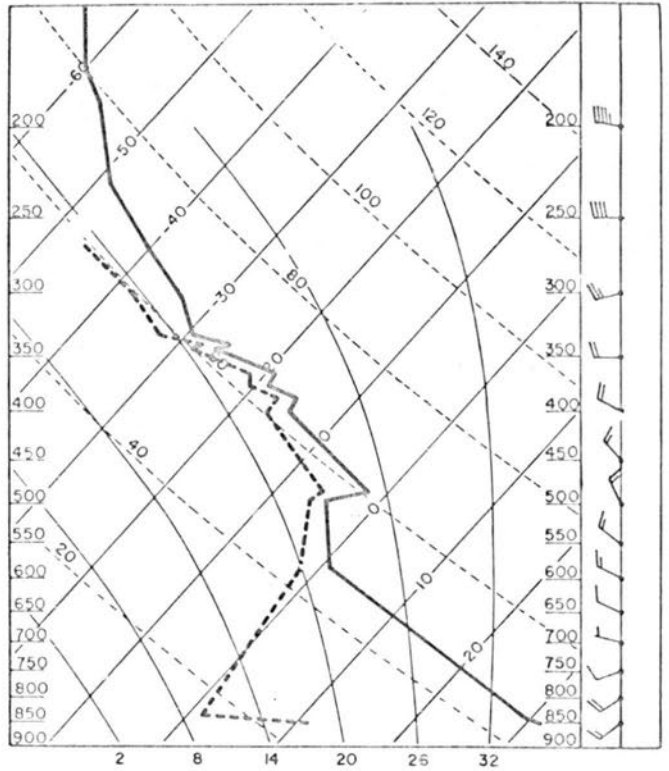
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

8 July 1964
Upper Air Soundings
Skew-T Diagrams

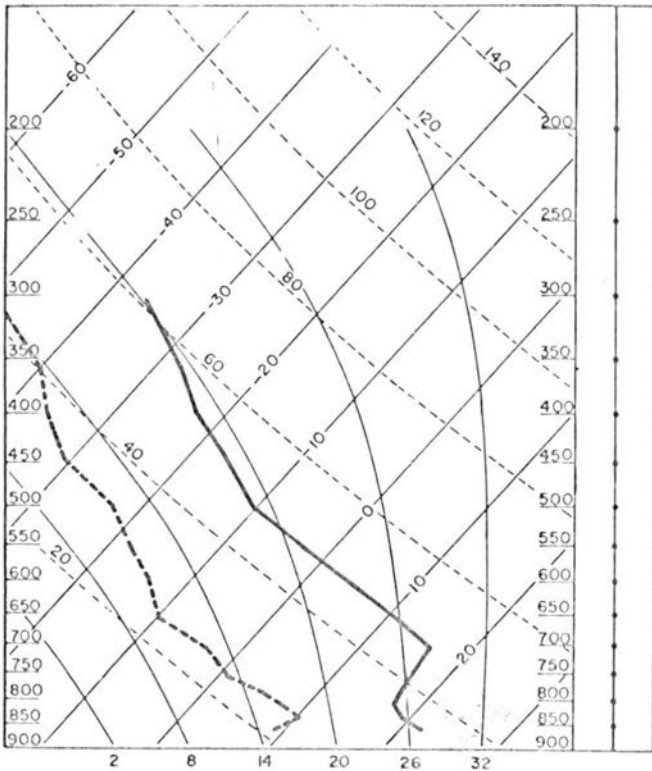
Figure G



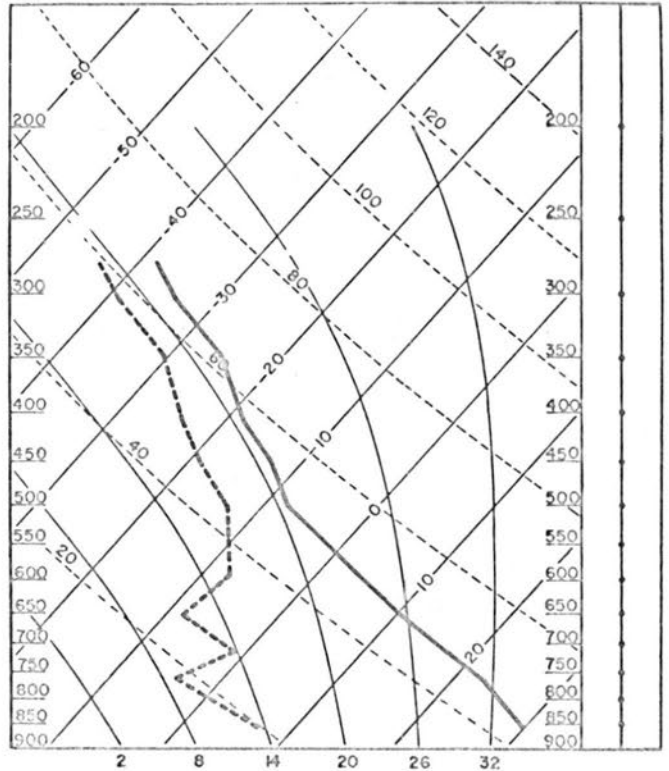
1. Denver, 0500 MST.



2. Denver, 1700 MST.



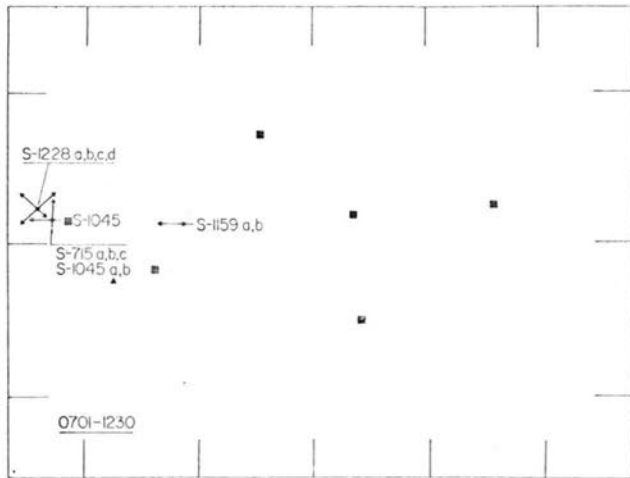
3. Fort Collins, 0857 MST.



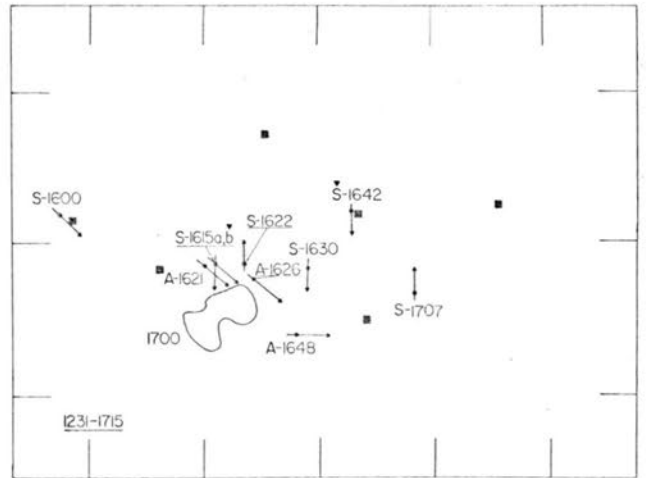
4. Fort Collins, 1657 MST.

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Photo Index

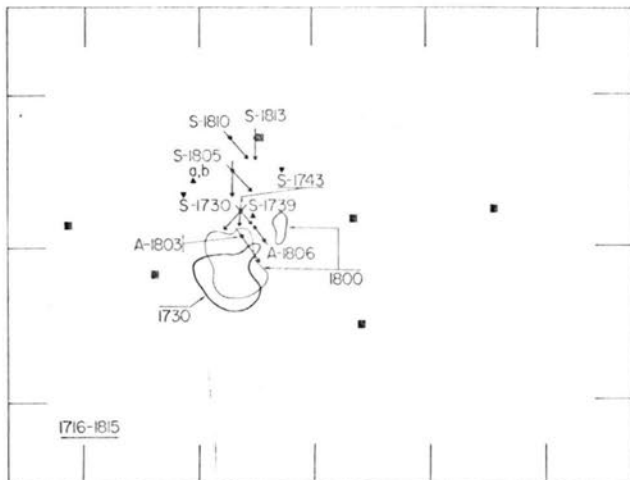
Figure H



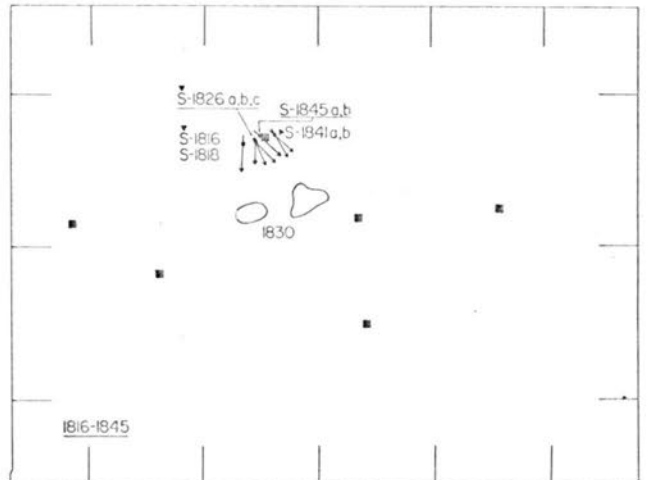
1.



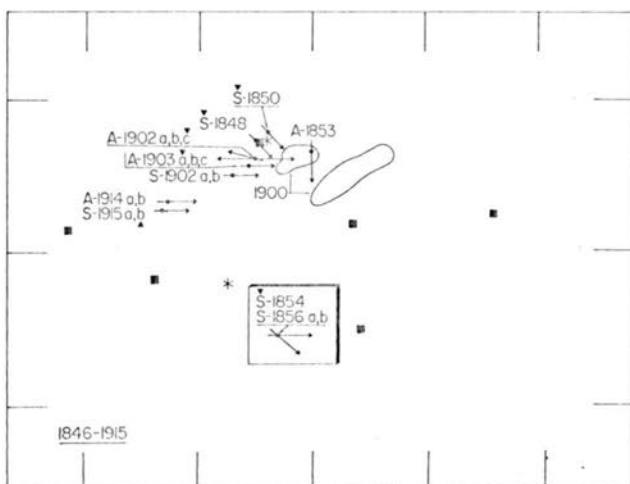
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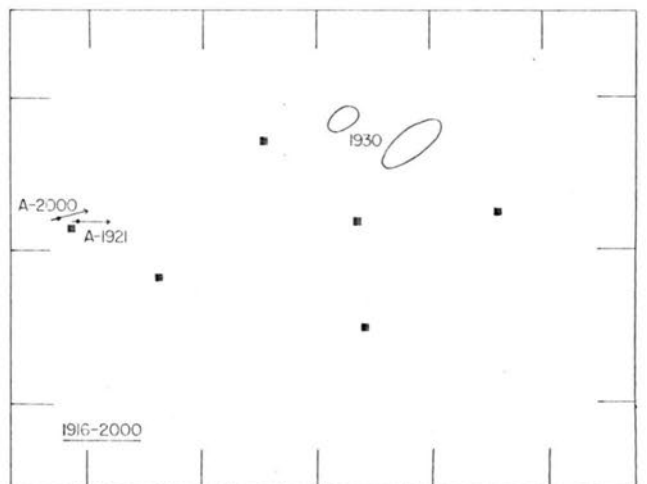
3.



4.



5.



6.

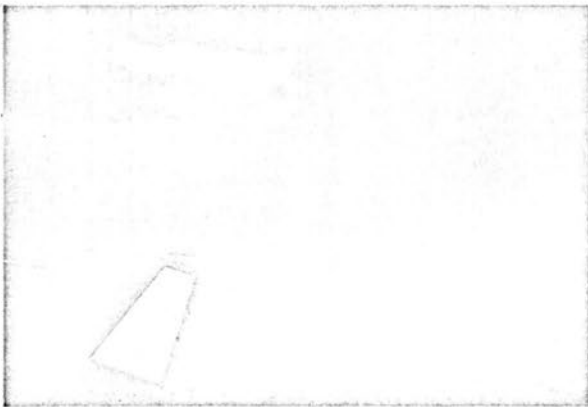
8 July 1964
Selected Photos



S-1045a Cement plant north of Fort Collins. Note relatively dirty air.



S-1045 Building cumulus west of Fort Collins over mountains.



S-1159a West from east Ault. Note dirty air to west.



S-1615b Looking southeast from east of Greeley at growing cumulus.



S-1642 Area of growing cumulus south of New Raymer.



S-1730 Test cell beginning to grow rapidly.

8 July 1964
Selected Photos



S-1739 Extreme west edge of test cell twenty-one minutes prior to beginning of operation.



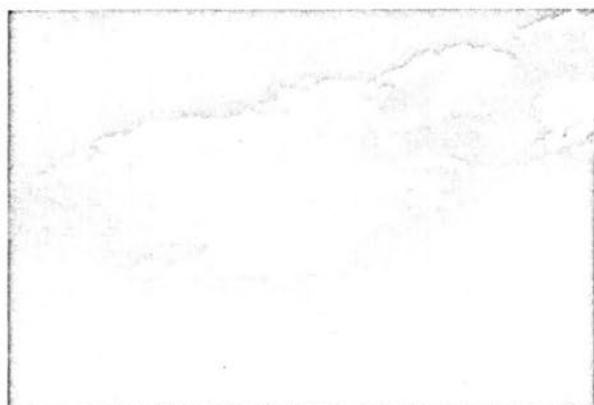
S-1743 Building cumulus on the northwest side of test case.



S-1805a Test case five minutes after operation beginning. Note small cumulus below cloud base. Very good up air near these.



S-1816 Looking south at the test cell. The original cell has split, this being the west part.

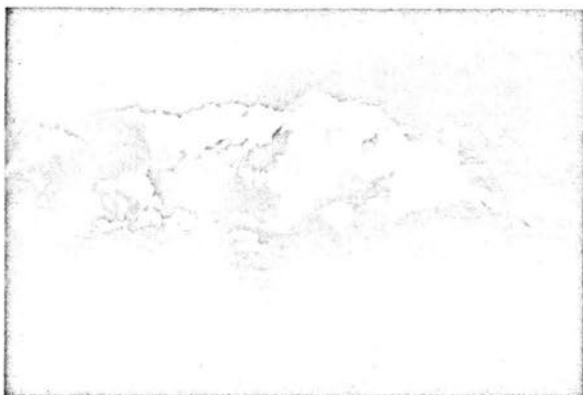


S-1826a Looking southeast at the area between the two cells. Note lenticular clouds in the center of the photo.



S-1826b Looking at the leading edge of the test cell. Lenticular clouds on the left.

8 July 1964
Selected Photos



S-1826c Major area of test cell. Note well defined shape of clouds.



S-1841a General shot of area between the two cells, test cell on right. "Roll cloud" along leading edge barely visible.



S-1841b Test cell. Note light icing around the center of the cell and the "roll cloud" in the lower left of photo.



S-1848 Test cell. Note icing at upper levels of the cloud. Heavy precipitation reaching the surface.



S-1850 Top of test cell. Note icing.

8 July 1964
Selected Photos



S-1854 Looking east at the left flank cloud.



A-1902c Center of test case seven (7) minutes after termination of test case.



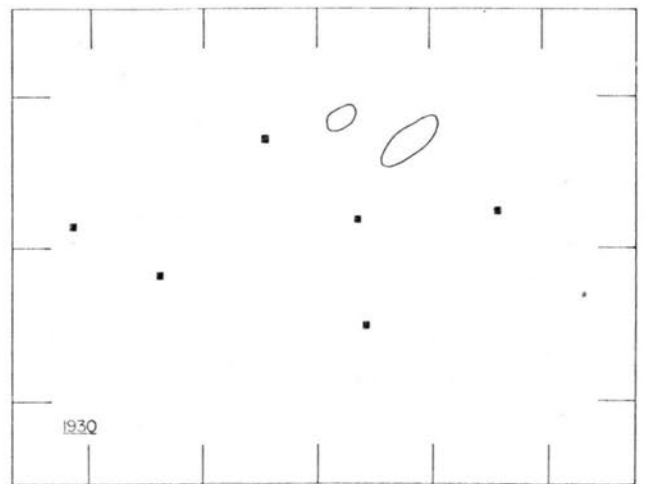
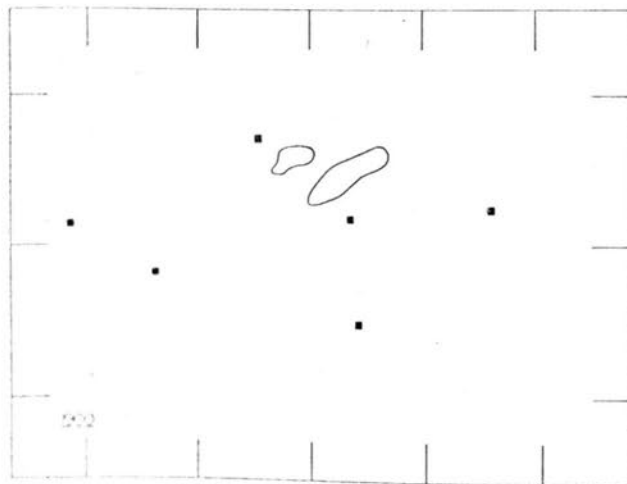
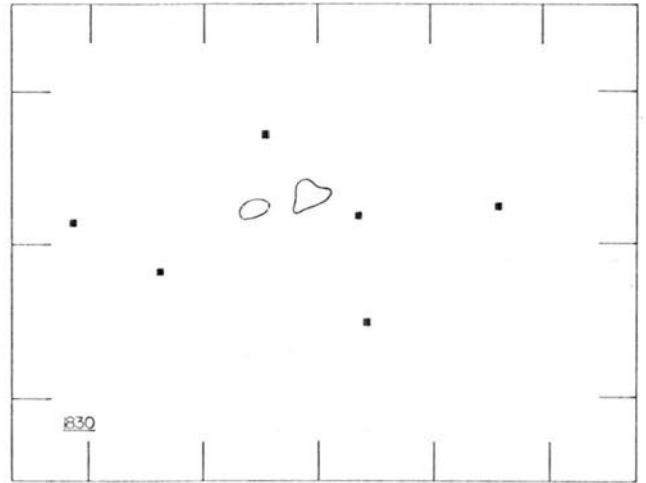
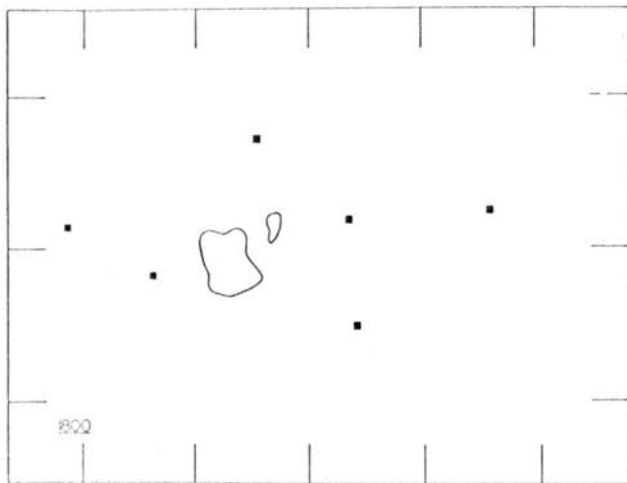
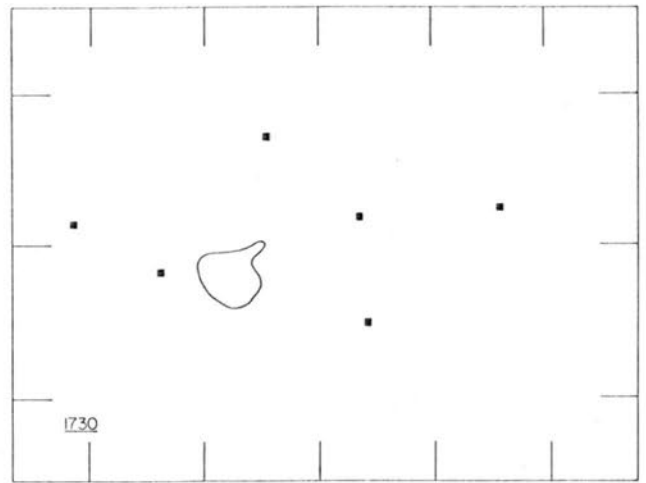
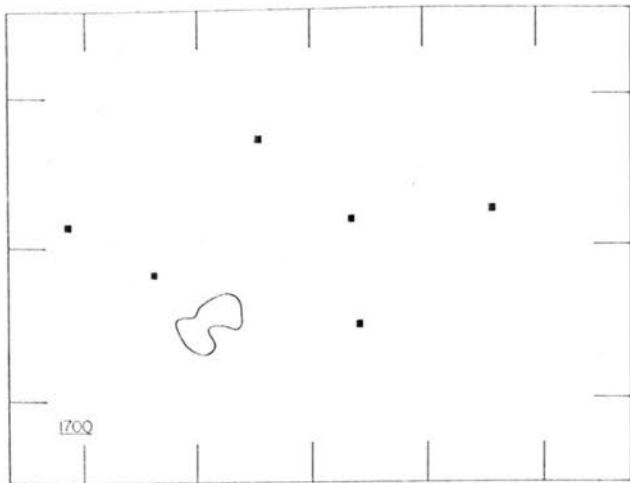
A-1903a Eight (8) minutes after termination of operation. Note heavy cirrus shield.



S-1915b General area of test case twenty (20) minutes after termination of operation.

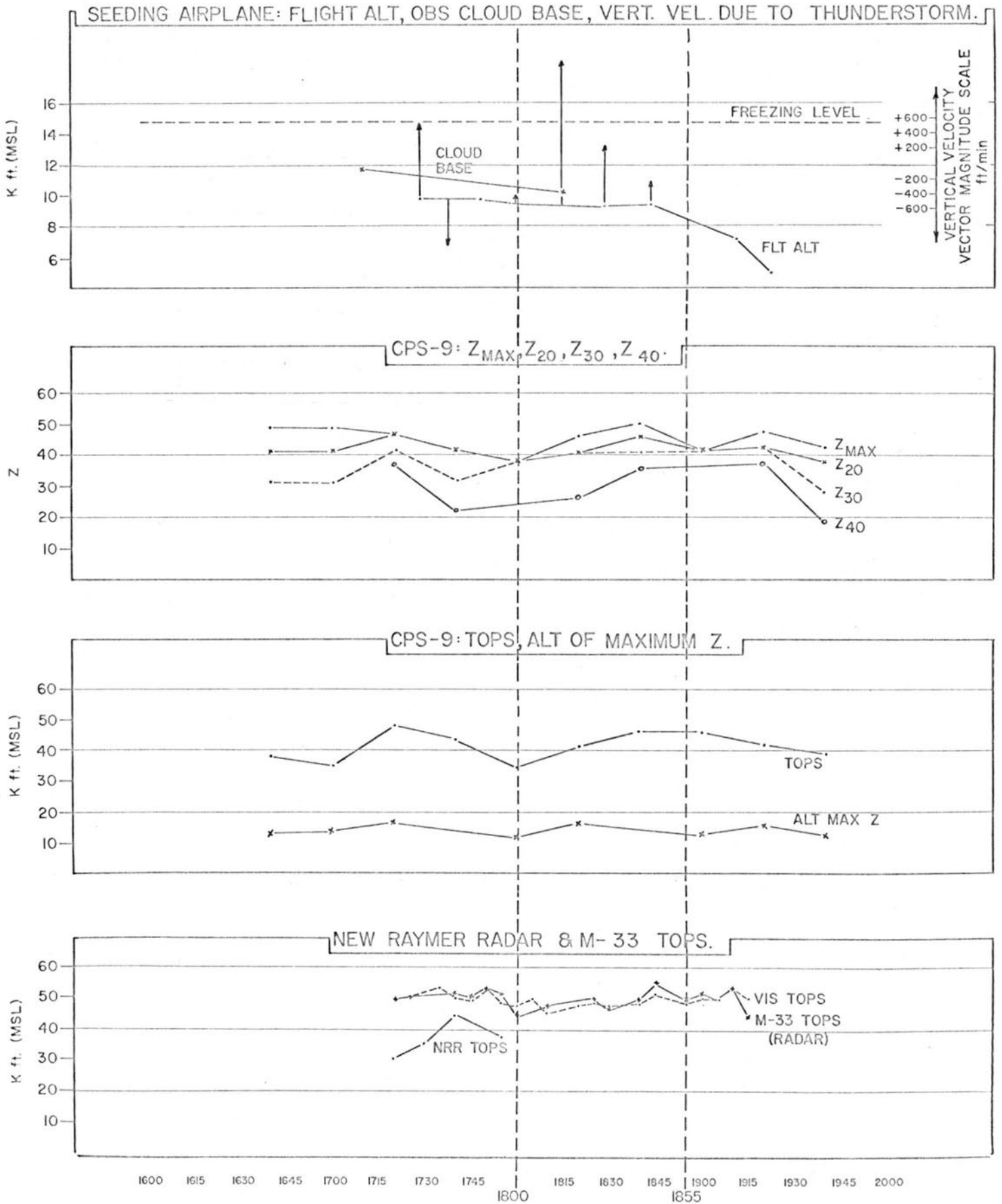
8 July 1964
Radar Echo Positions

Figure I



8 JULY - 1964

FIGURE J



TEST CASE OF 9 JULY 1964

Test Case Began 1812 MST, Ended 1915 MST
 Seeded: NO Material Used: None
 Rate of Seeding: None Equipment Used: None

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/2	1	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	42,000	2	38,000	1	39,000	2
Radar tops K-ft MSL, NRR	42,750	2	36,667	3	37,000	2
CPS-9 radar reflectivity, Z ₃₀	39	2	39	1	29.5	2
Area covered by radar echo, mi ²	147	1	162	1	258	1
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	360	5	675	4	380	5

SIGNIFICANT FEATURES

The surface weather map showed a weak pressure gradient over eastern Colorado and a ridge at 500 mb. The jet stream entered the Pacific coast and southern California and extended to central Montana and curved anti-cyclonically through eastern Nebraska.

All equipment and personnel were in the field and operating during this test case. Due to increasing cloud cover throughout the test case, it was not possible to obtain very many good photos.

Both the seeding and the observation airplanes experienced moderate to severe turbulence in the vicinity of the test case. It was finally discovered by the seeding aircraft, with the aid of the New Raymer radar, that most of the turbulence could be avoided and better upair could be attained by pro-

ceeding much farther ahead of the precipitation core than usual.

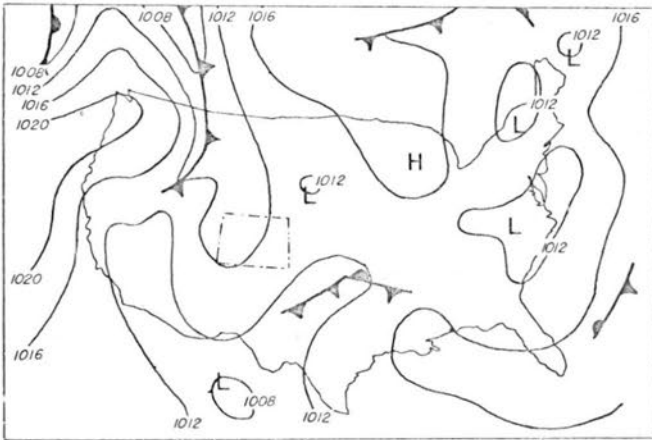
The radar tops and reflectivity remained essentially constant throughout the test case.

The test case was the only significant thunderstorm in the area on this day. There was much more rain and hail produced by the test case than is indicated in Figures M and O due to the lack of observers in this area. The seeding aircraft did observe hail on the ground early in the test case.

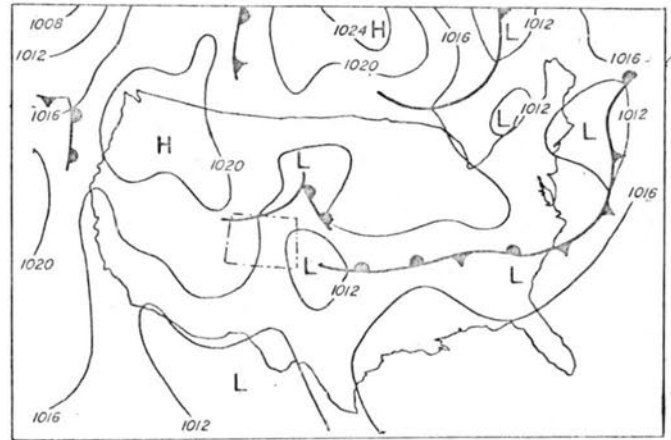
After only six minutes of limited generator operation, one generator failed. Due to the fact that part of the other generator had been lost in severe turbulence the day before, the seeding airplane was unable to seed this test case; and it was taken as a "no seed" case.

9 July 1964
 U. S. Weather Bureau Synoptic Data

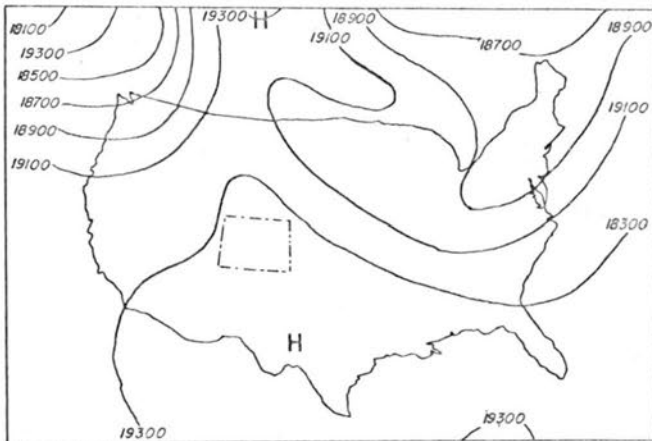
Figures A - F



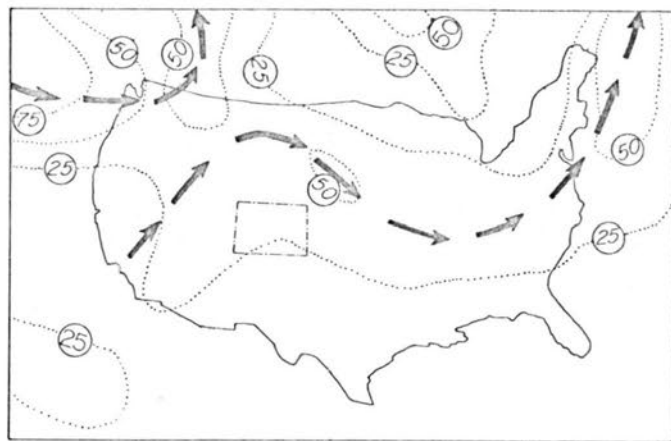
A. Surface Weather Map, 1100 MST (day of test case).



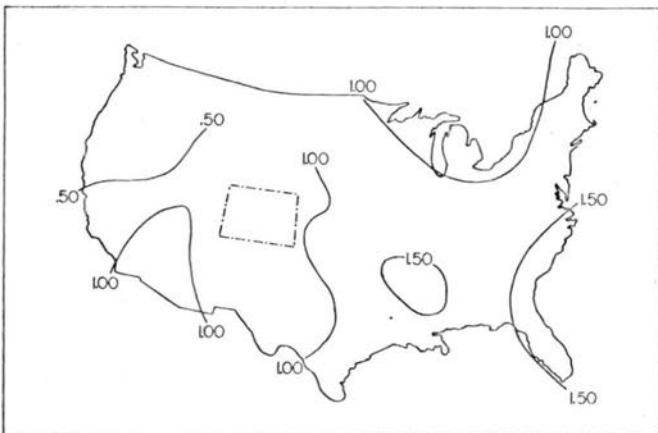
B. Surface Weather Map, 1100 MST (day following test case).



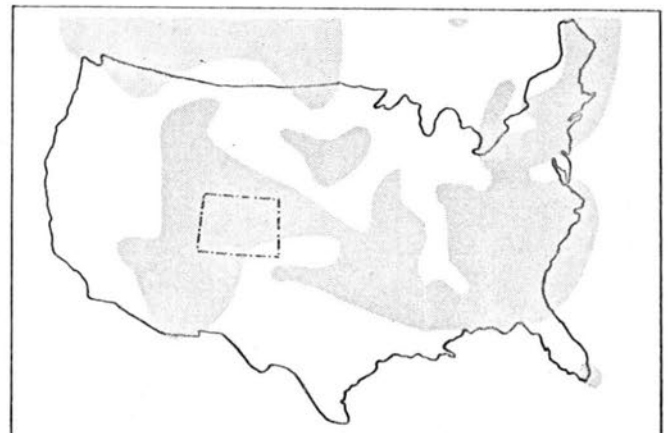
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



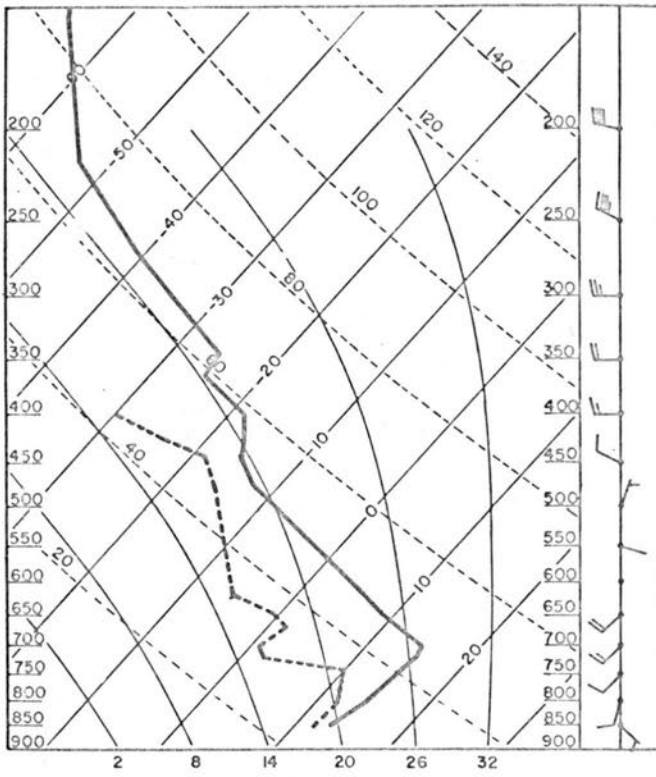
E. Precipitable Water, Inches, 1700 MST.



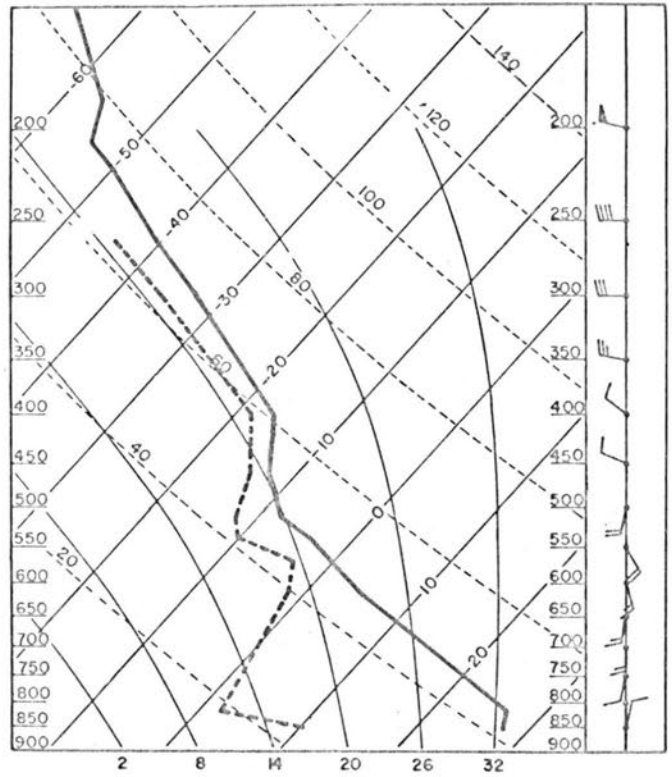
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

9 July 1964
Upper Air Soundings
Skew-T Diagrams

Figure G



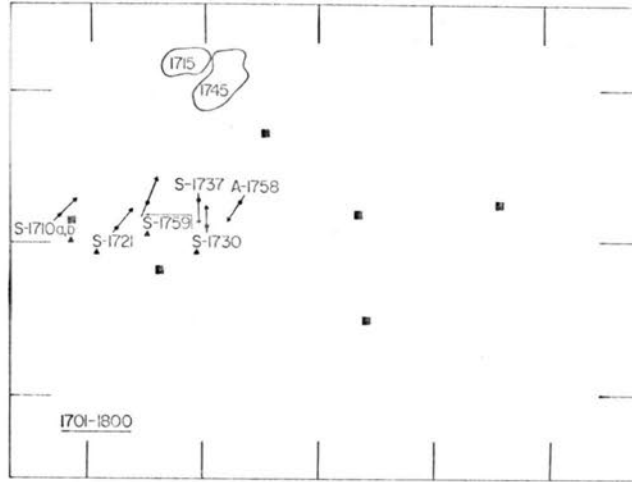
1. Denver, 0500 MST.



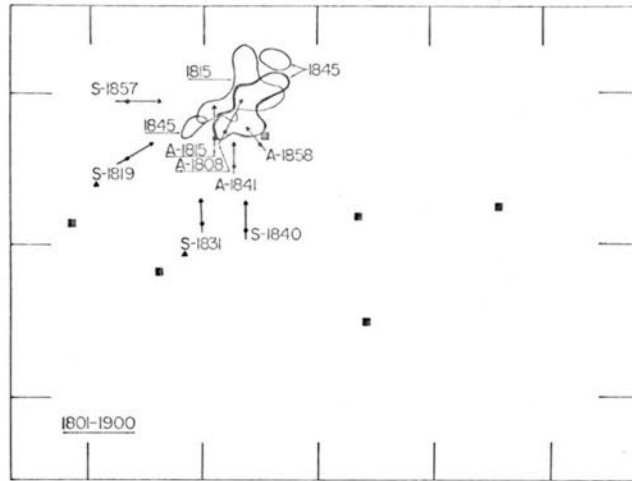
2. Denver, 1700 MST.

9 July 1964
Photo Index

Figure H



1.



2.

9 July 1964
Selected Photos



S-1710b Test case as seen from Fort Collins one hour and two minutes before operation began.



S-1721 Fifty-one minutes before test case began; local heavy rain and hail.



S-1730 Looking north at the test case. Many other small clouds in area obscuring test case.



S-1759 Test case growing rapidly. Severe turbulence along base of cell.



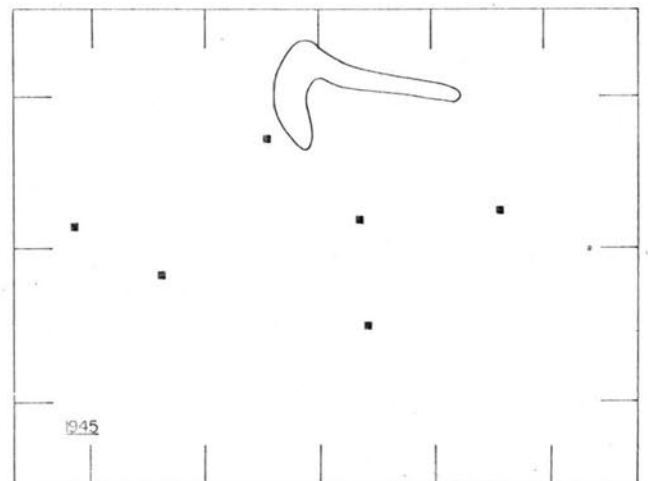
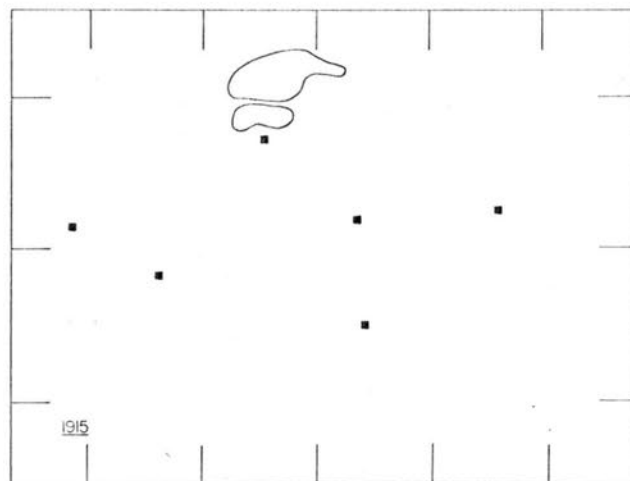
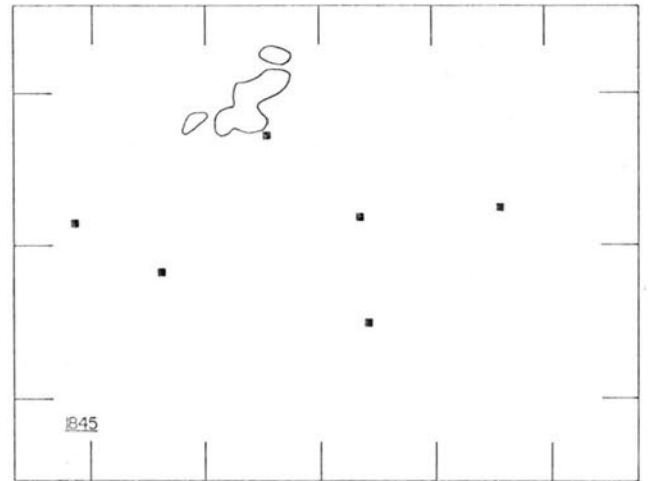
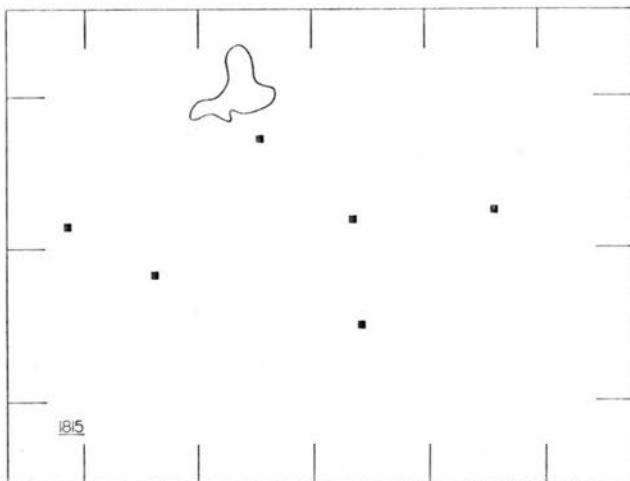
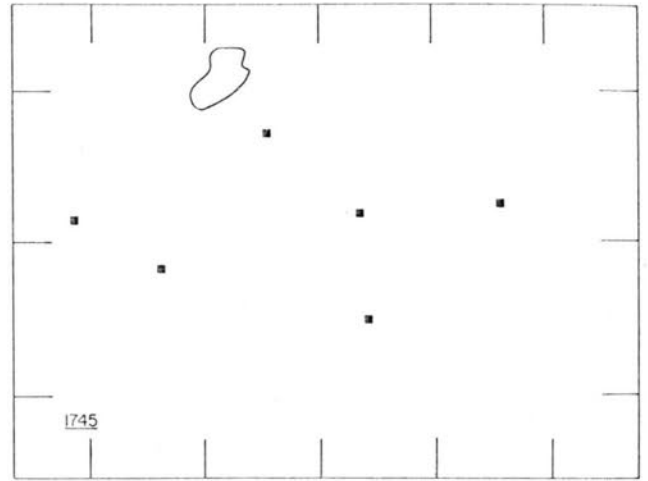
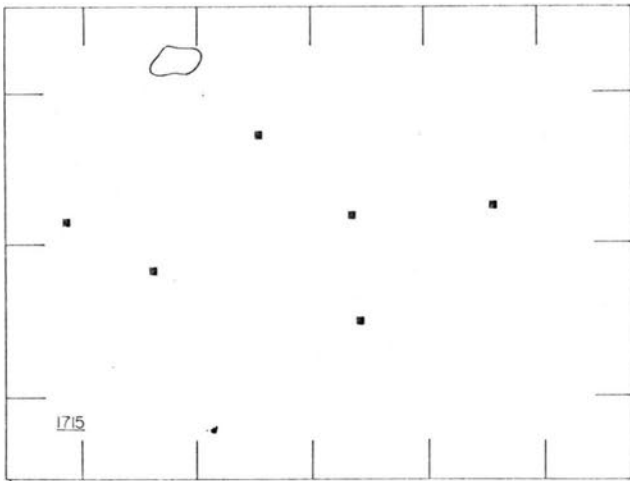
S-1819 Heavy precipitation falling from test case. Slow moving cell producing a great deal of localized precipitation.



S-1831 Heavy precipitation and severe turbulence. Extensive cloud cover over the area.

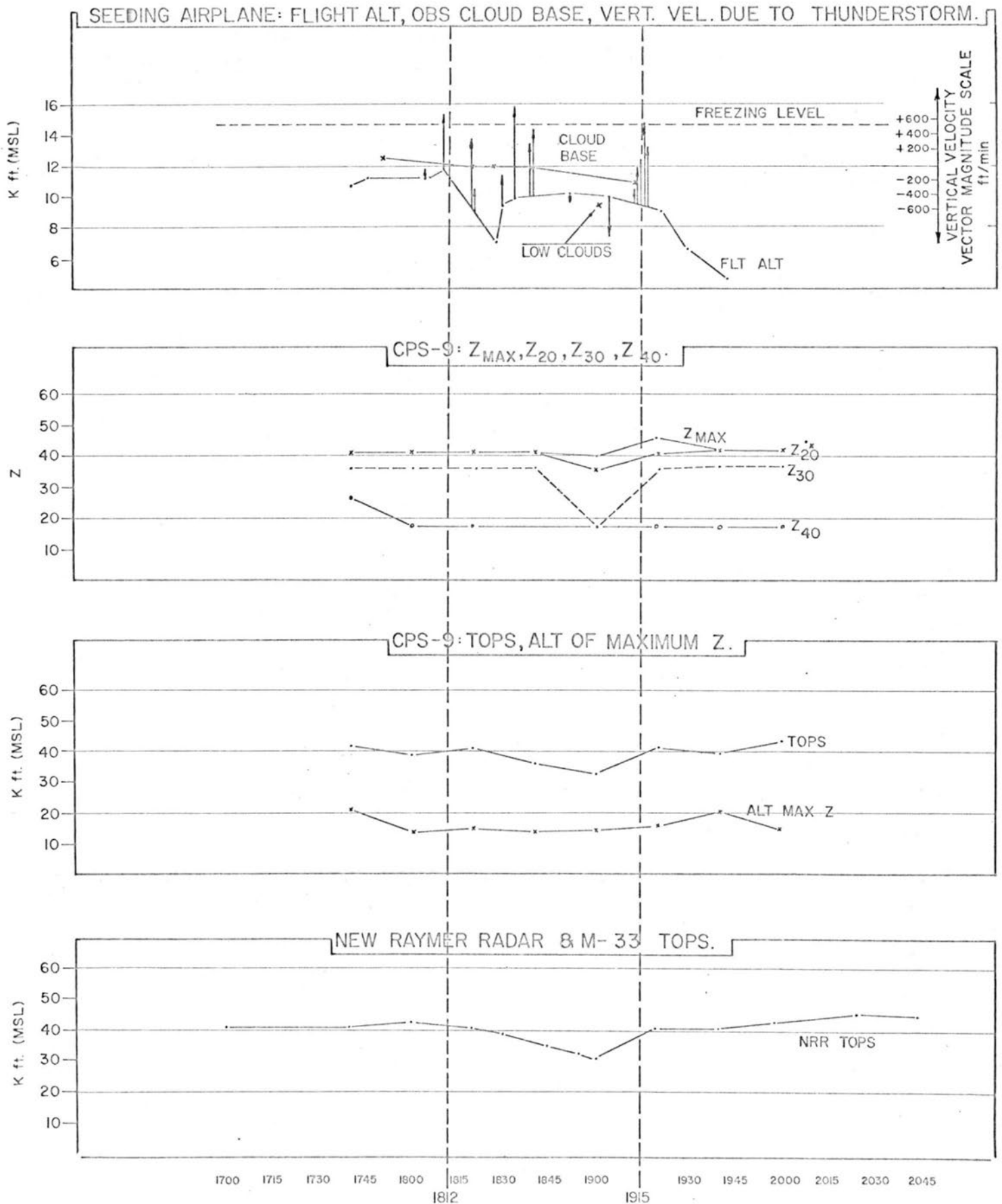
9 July 1964
Radar Echo Positions

Figure I



9 JULY-1964

FIGURE J



TEST CASE OF 27 JULY 1964

Test Case Began 1745 MST, Ended 1845 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 7.7 gms/min. Equipment Used: Lohse Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/2	1	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	40,000	1	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	38,667	3	35,000	2
CPS-9 radar reflectivity, Z ₃₀	30	1	NA	0	NA	0
Area covered by radar echo, mi ²	215	1	248	1	114	1
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	700	1	1,225	4	600	7

SIGNIFICANT FEATURES

The thunderstorm used as a test case on this day appeared to be associated with the development of a weak frontal system over northern Colorado. There was enough moisture aloft to support the development of thunderstorms.

All equipment and personnel, except the M-33, were operational during this test case. The radar echo was out of range of the CPS-9 radar during its later stages so there was little data from this source. The M-33 radar had mechanical problems during the test case and, hence, was unable to obtain any radar data. The M-33 radar did, however, obtain visual tops for the test case.

The test case was observed to have been composed of a high density of ice crystals in the upper layers early in the test case. This was typical

of all thunderstorms during this period. The thunderstorms grew and dissipated very rapidly with much icing in the upper levels.

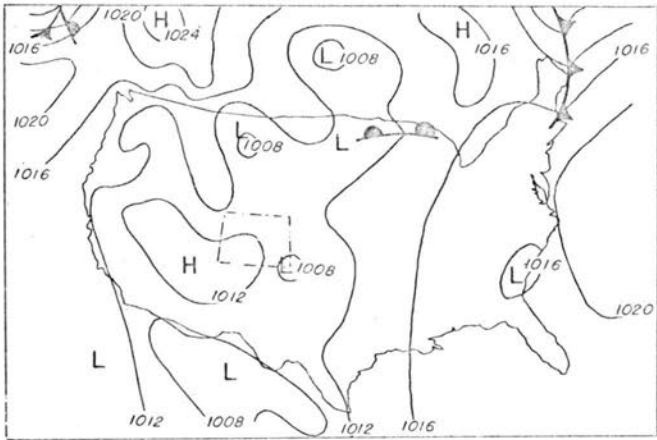
There was a great deal of strong convective activity before and during this test case as demonstrated by an observed dust cloud extending from the surface to approximately 4,000-5,000 feet above ground level. The cloud base was observed to have been 15,500 feet msl at the beginning of the test case and to lower to 13,000 feet msl later in the test case.

The updrafts remained very good throughout the test case.

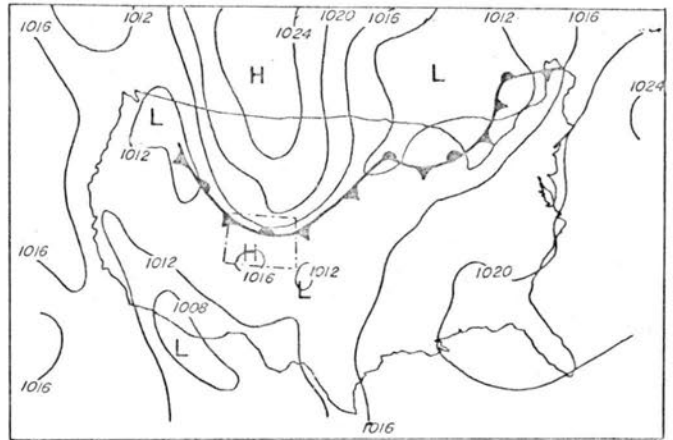
There was moderate cumulus activity in north-eastern Colorado with very little rain or hail reaching the ground.

27 July 1964
 U. S. Weather Bureau Synoptic Data

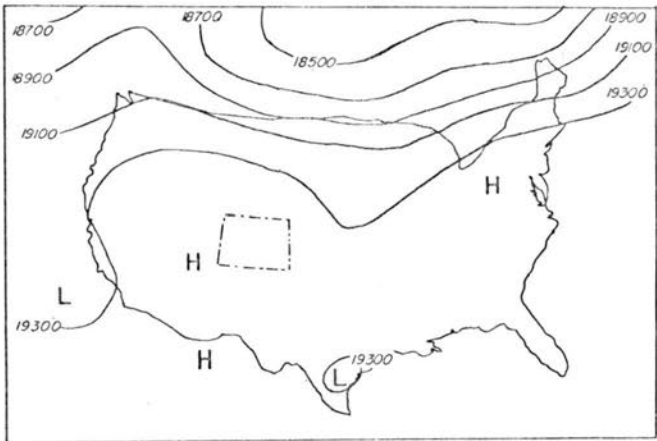
Figures A - F



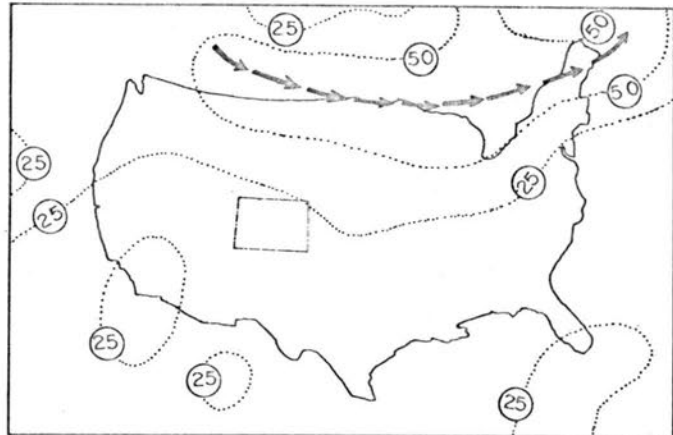
A. Surface Weather Map, 1100 MST (day of test case).



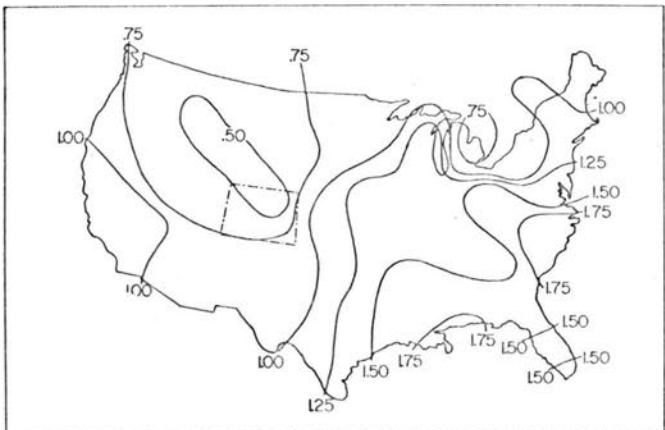
B. Surface Weather Map, 1100 MST (day following test case).



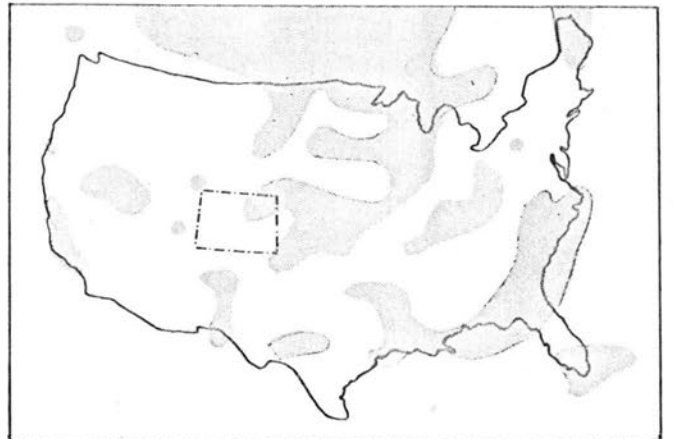
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



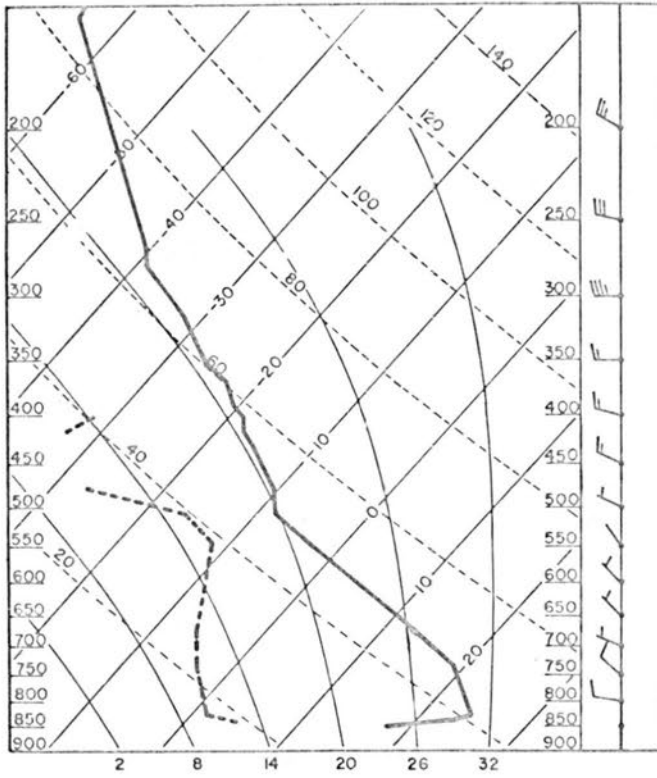
E. Precipitable Water, Inches, 1700 MST.



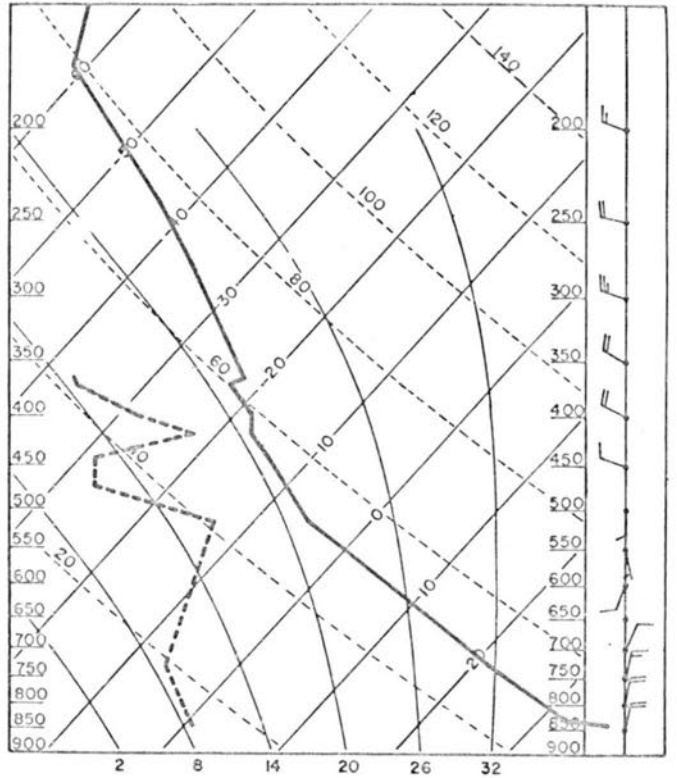
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

27 July 1964
Upper Air Soundings
Skew-T Diagrams

Figure G



1. Denver, 0500 MST.

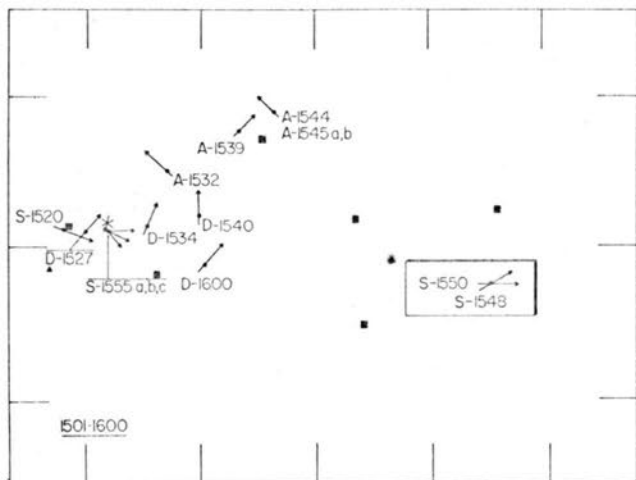


2. Denver, 1700 MST.

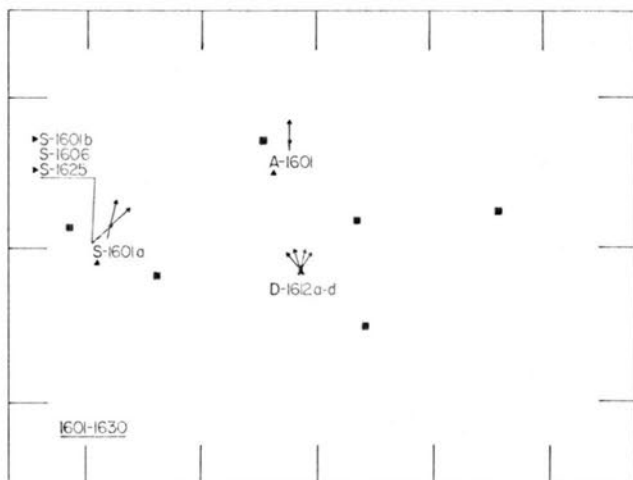
27 July 1964

Photo Index

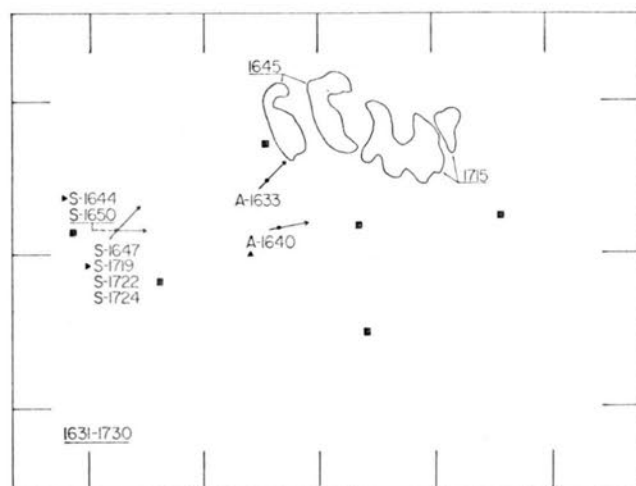
Figure H



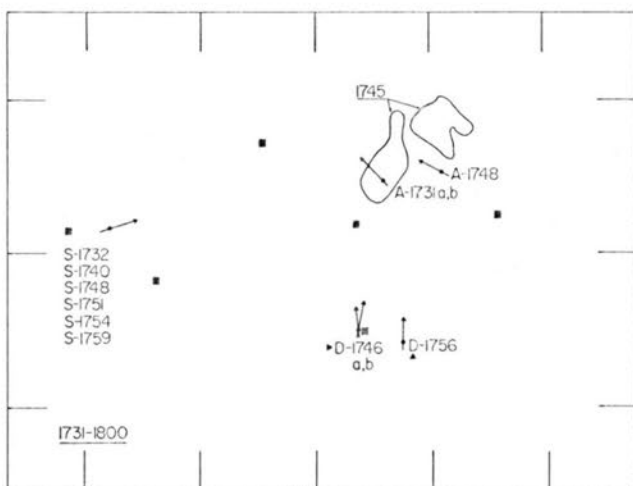
1.



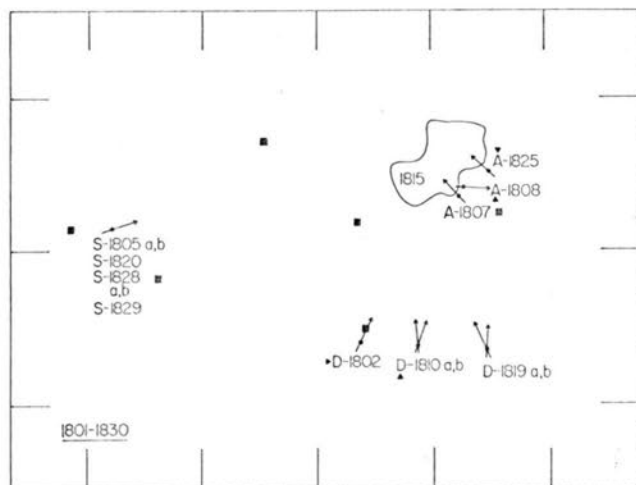
2.



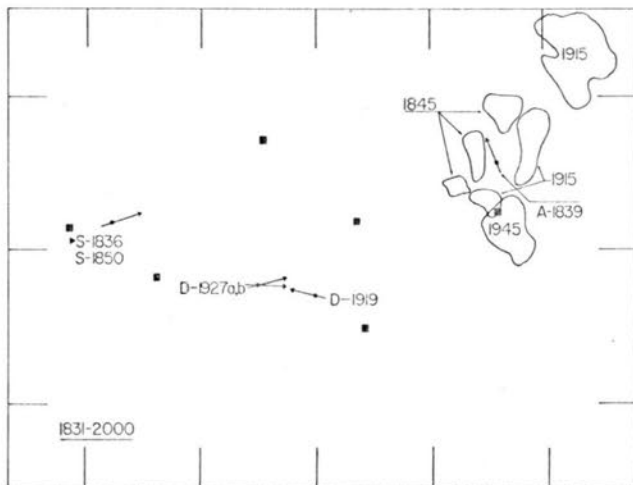
3.



4.



5.



6.

27 July 1964
Selected Photos



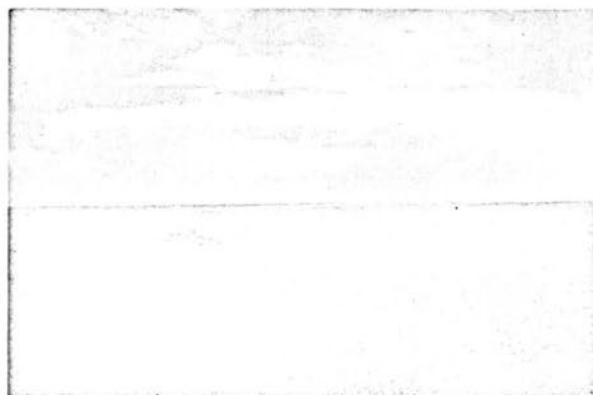
D-1527 Large cumulus southeast of Cheyenne; did not develop as a test case.



S-1601 a, b Large cumulus southeast of Cheyenne, dissipating slightly.



A-1601 Dust cloud 4,000-5,000 feet above the surface below the cell in the previous pictures.

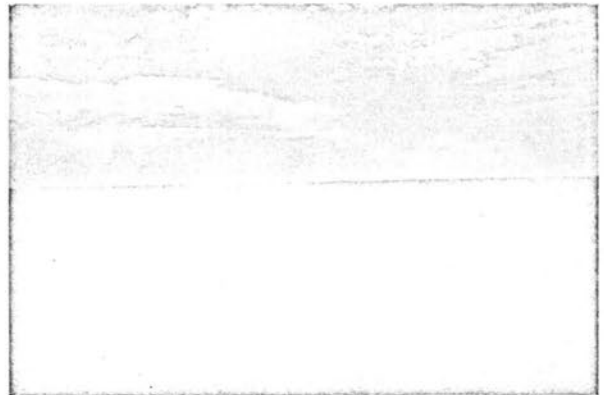


S-1625 Same large cumulus southeast of Cheyenne still dissipating.

27 July 1964
Selected Photos



A-1640 Test case developed in this area and to the left.



S-1644 Area in which test case developed as seen from the M-33.



S-1719 Test case developed on the extreme right.



D-1746a, b Area of test cell one minute after operation began. Note extensive icing.

27 July 1964
Selected Photos



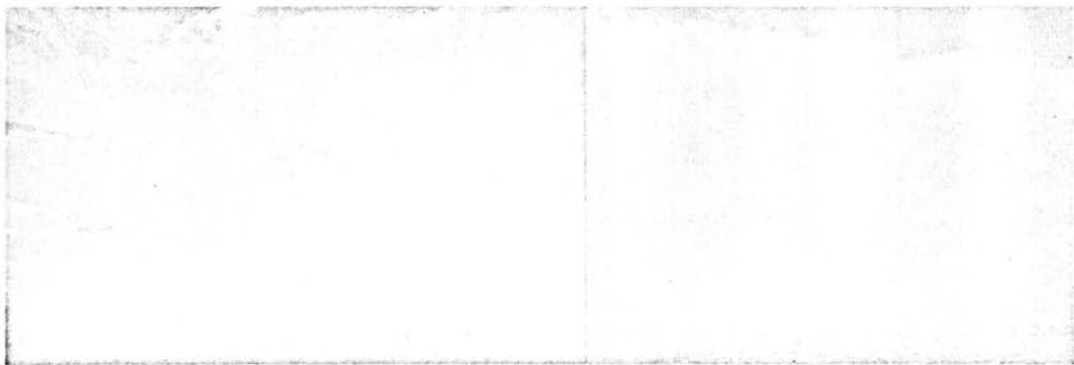
D-1756 West half of test cell and area of precipitation, cells built and dissipated rapidly.



D-1802 General area of test case seventeen minutes after operation began.



A-1808 Looking east from under the test cell.



D-1810a, b Test cell twenty-one minutes after operation began.

27 July 1964
Selected Photos



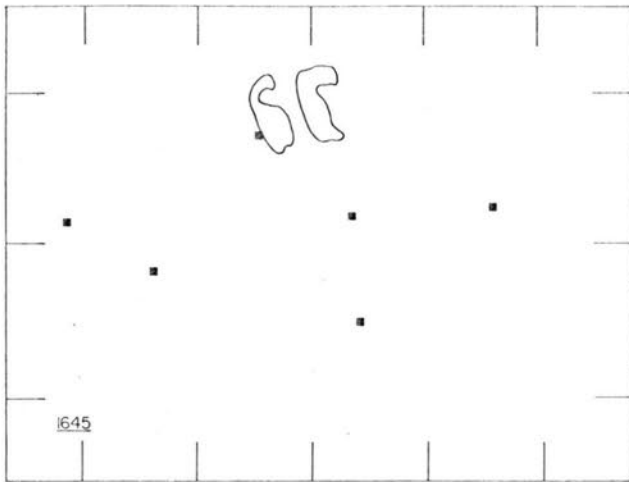
A-1825 Northeast edge of test case as seen from under the test cell. Note moderate precipitation reaching the ground.



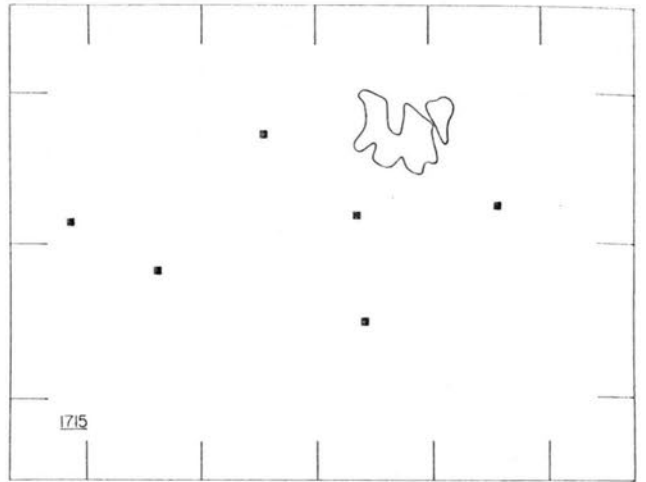
S-1836 General area of test case and other cells in the area nine minutes before operation ended.

27 July 1964
Radar Echo Positions

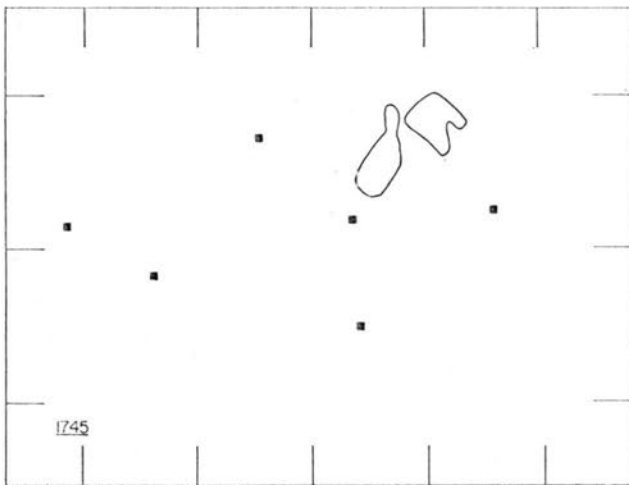
Figure I



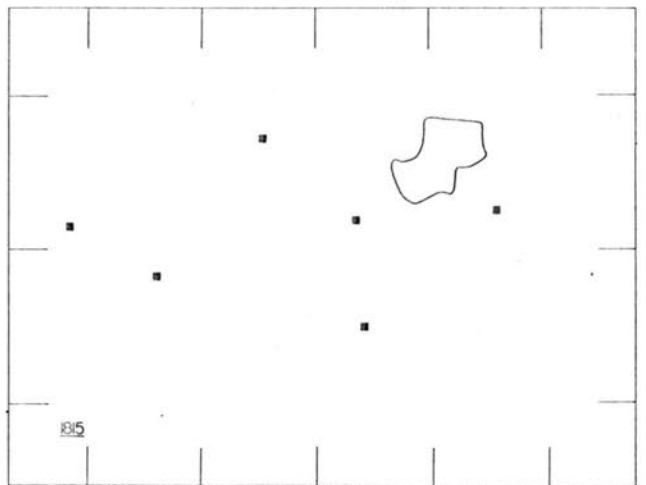
1.



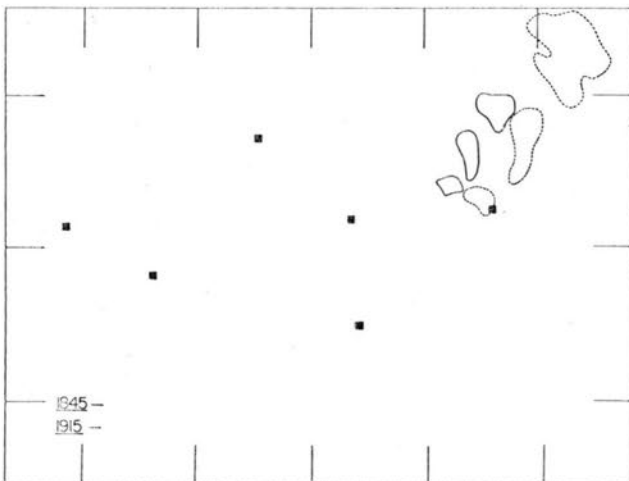
2.



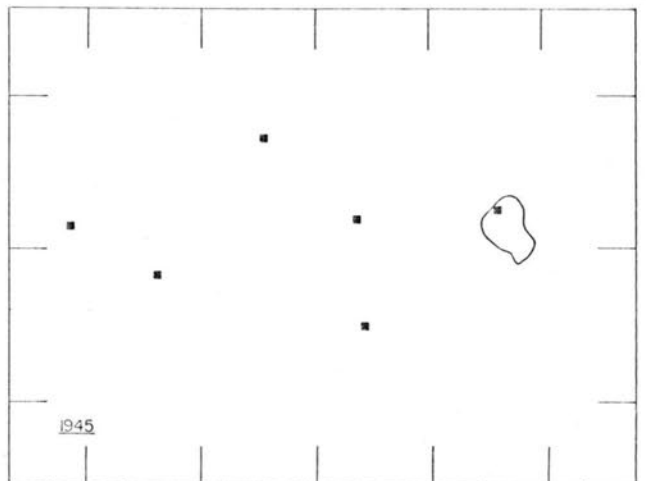
3.



4.



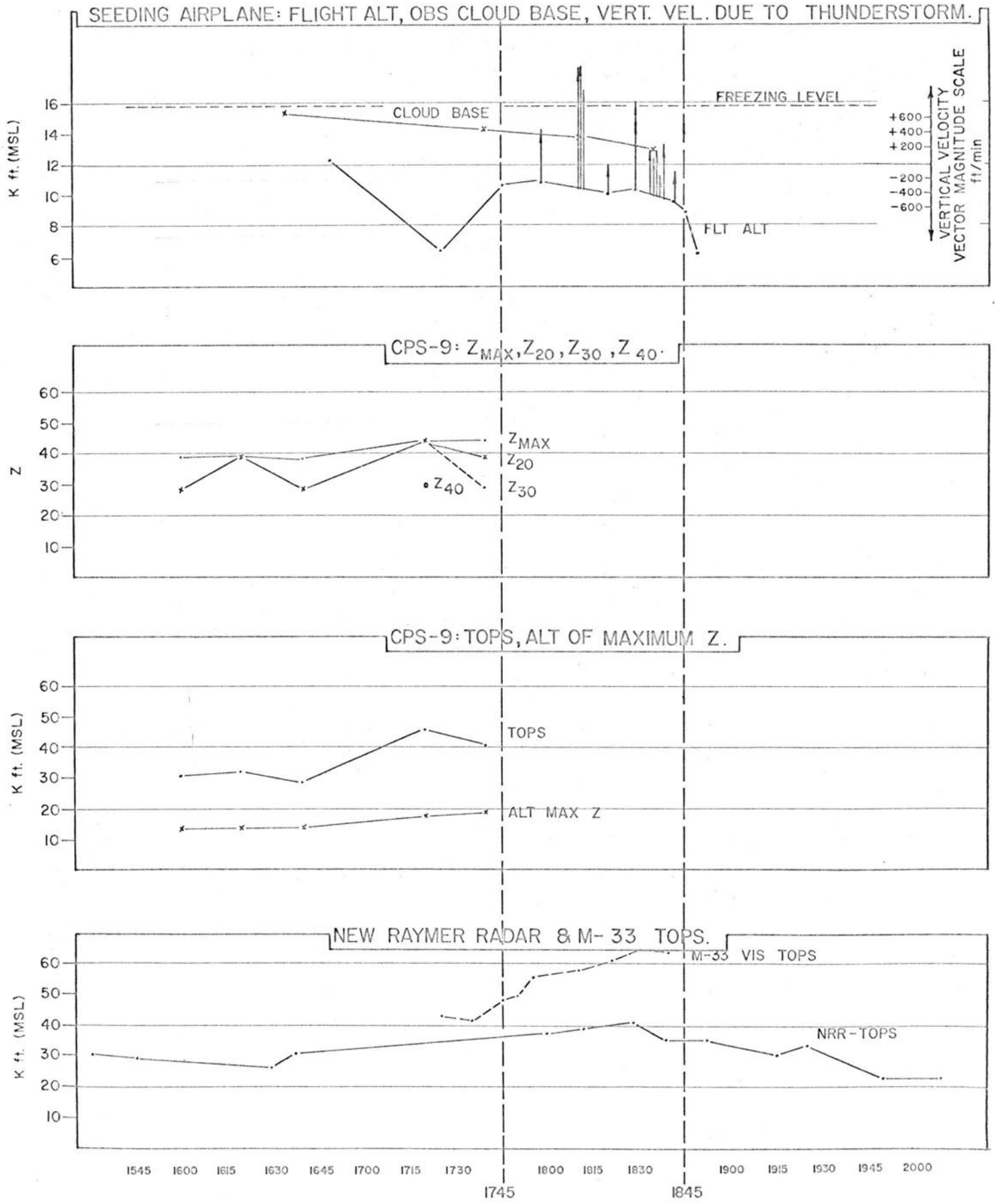
5.



6.

27. JULY-1964

FIGURE J



TEST CASE OF 30 JULY 1964

Test Case Began 1645 MST, Ended 1746 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 7.7 gms/min. Equipment Used: Lohse Generator

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	33,000	1	26,500	2	NA	0
Radar tops K-ft MSL, NRR	29,000	1	29,000	2	25,167	3
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	112	1	162	1	195	1
Rainfall-volume, acre-feet	8.5		8.7		0.8	
Maximum updraft, ft/min.	814	7	780	5	-33.3	6

SIGNIFICANT FEATURES

Northeastern Colorado remained in the warm sector in advance of a Pacific front extending from eastern Montana into northern Utah. Upper level wind flow was anti-cyclonic and from the west.

All equipment and personnel were in the field and operating during this test case.

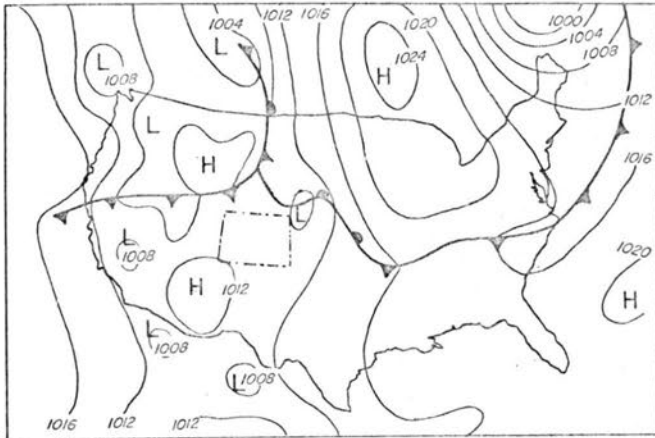
This test case was similar to the general trend of cumulus development in northeastern Colorado during the last one-half of July. The clouds grew and dissipated very rapidly and displayed a large amount of icing in the upper levels during the latter

stages of their lives. The cloud bases had also been very high for quite a number of days prior to this test case and on this day the trend continued. In general, the test case dissipated rapidly along with the other cumulus clouds in the area. The radar tops decreased and updrafts decreased throughout the duration of the test case.

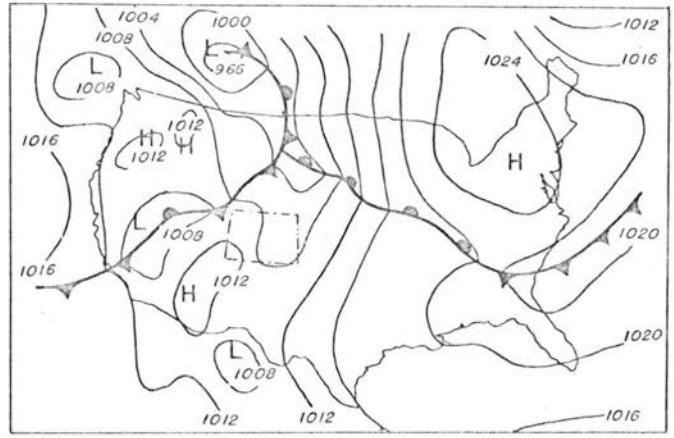
There were only a few cumulus buildups in northeastern Colorado during this test case day. These clouds produced no hail and only a very limited amount of rain.

30 July 1964
 U. S. Weather Bureau Synoptic Data

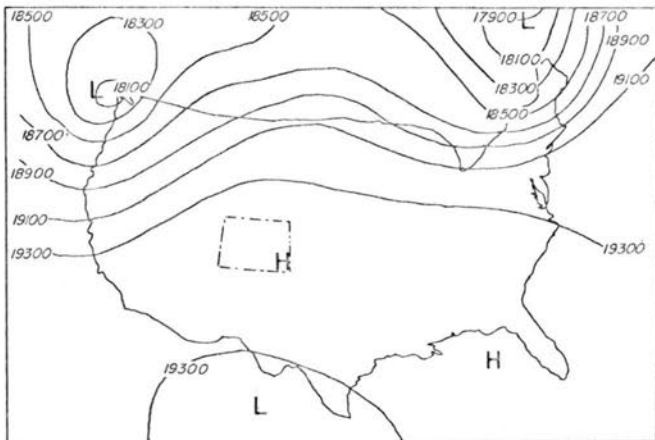
Figures A - F



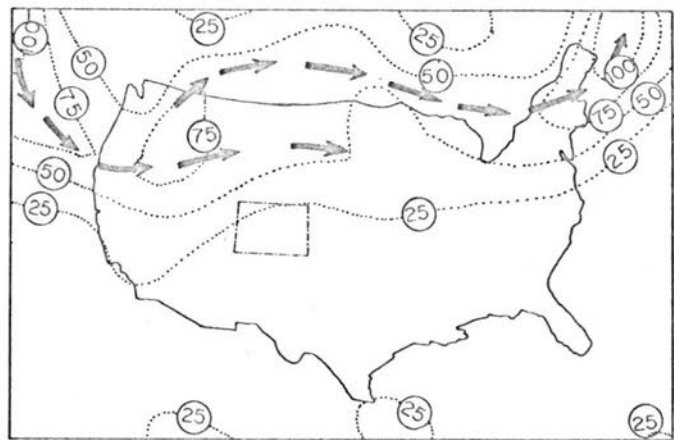
A. Surface Weather Map, 1100 MST (day of test case).



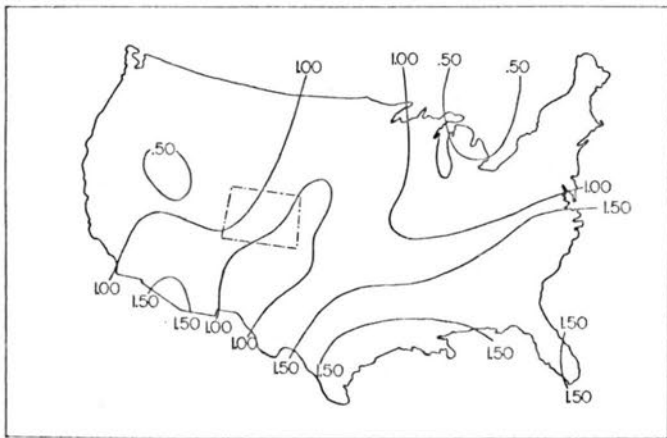
B. Surface Weather Map, 1100 MST (day following test case).



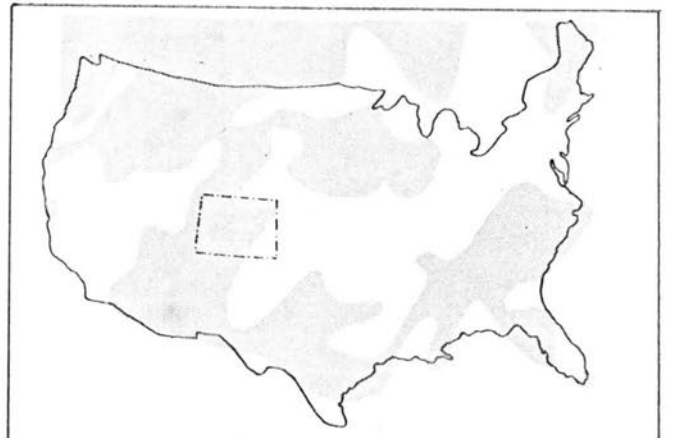
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



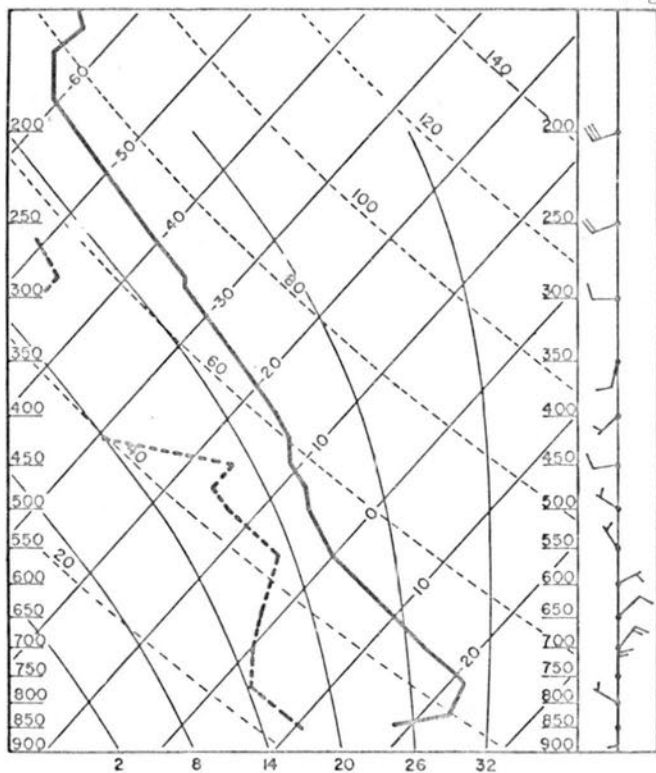
E. Precipitable Water, Inches, 1700 MST.



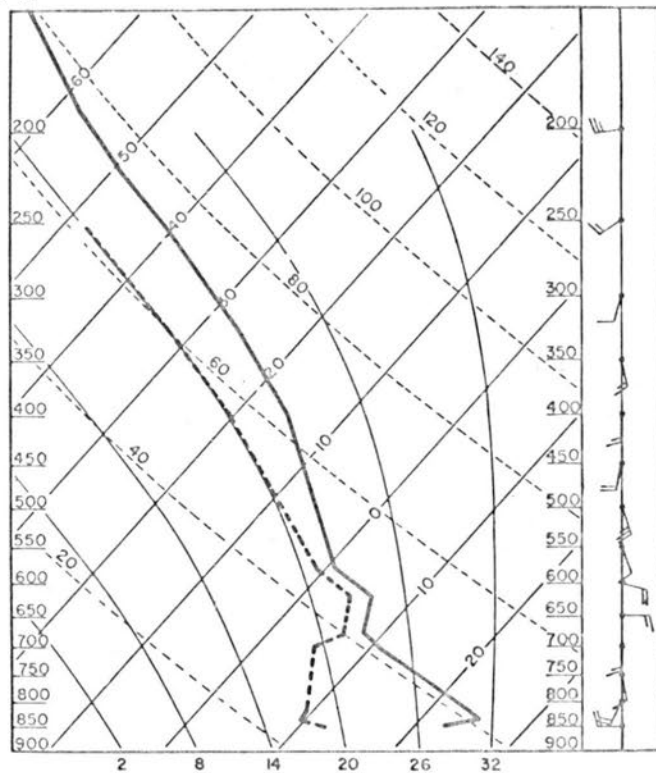
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

30 July 1964
Upper Air Soundings
Skew-T Diagrams

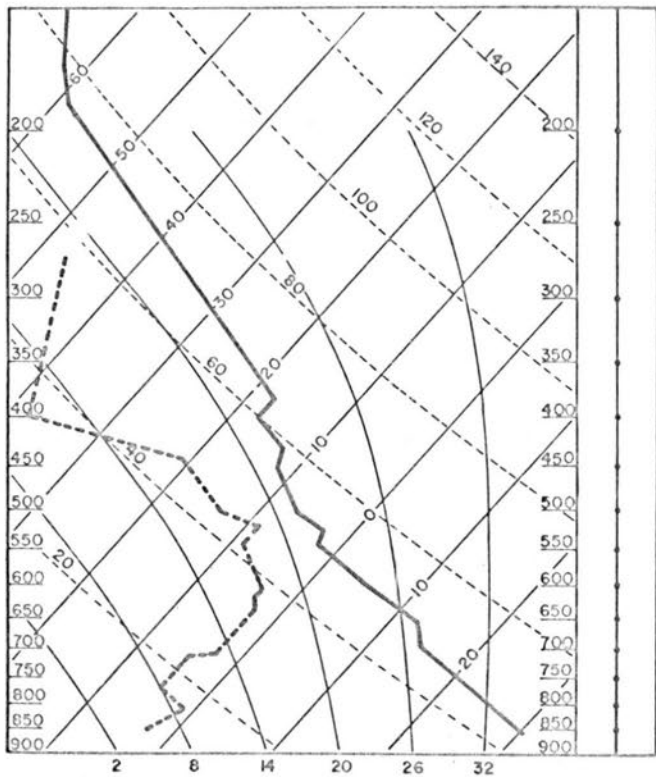
Figure G



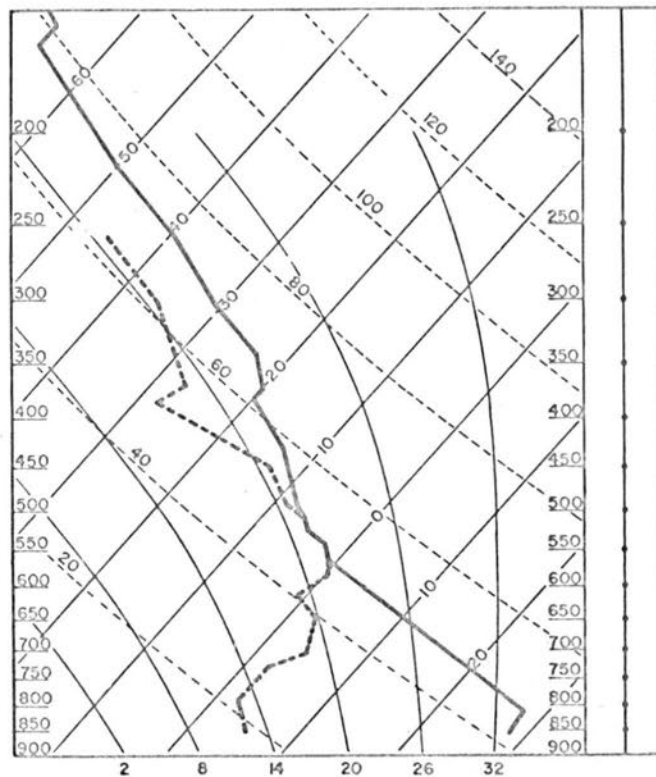
1. Denver, 0500 MST.



2. Denver, 1700 MST.



3. Fort Collins, 1215 MST.

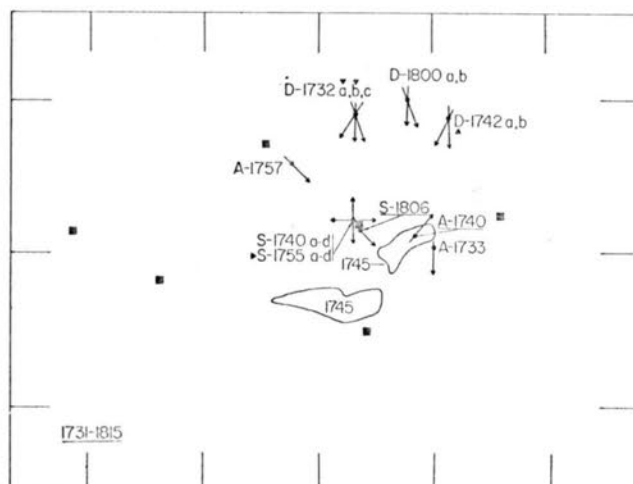
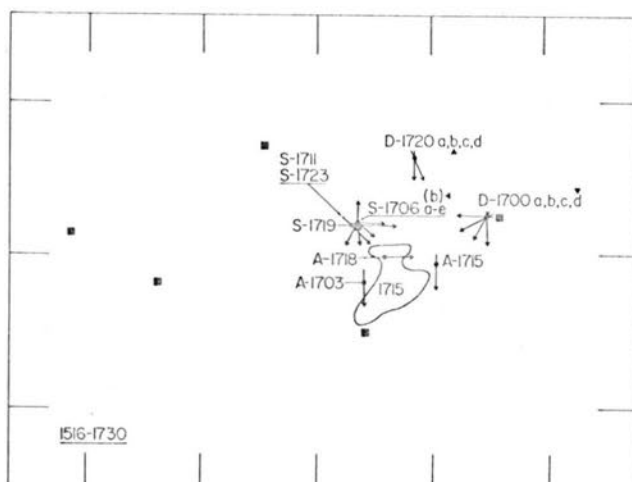
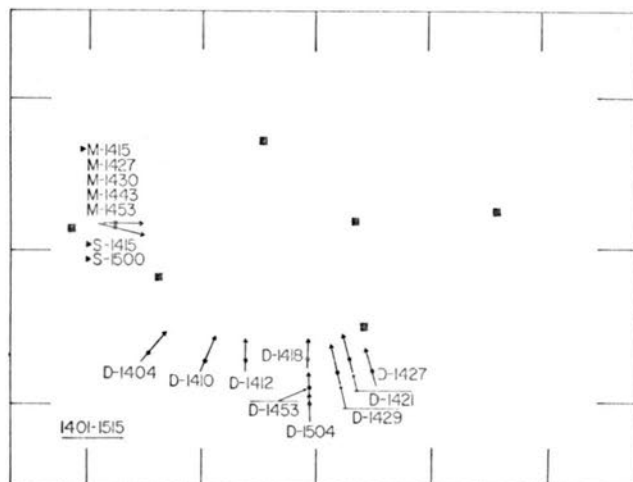
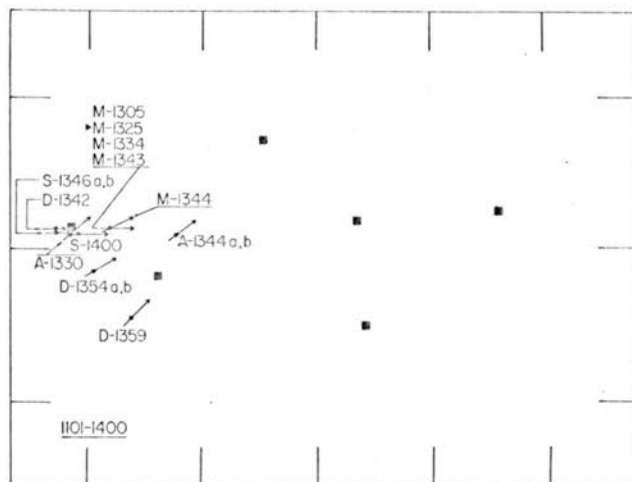
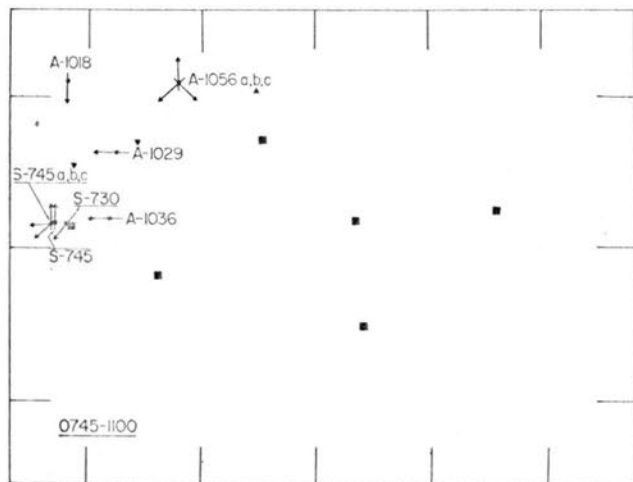


4. Fort Collins, 1715 MST.

30 July 1964

Photo Index

Figure H



30 July 1964
Selected Photos



S-0745b Cumulus clouds coming over Engineering Research Center, west of Fort Collins.



A-1029 Looking west at clouds coming over the mountains.



A-1056b Looking southwest from fifteen miles southeast of Cheyenne; relatively clear over the plains.



M-1325 Cumulus building northeast of M-33.



M-1415 Cumulus beginning to dissipate northeast of M-33. Most cells built and dissipated rapidly on this day.



S-1415 Looking east from M-33 at the southern edge of the dissipating cell.

30 July 1964
Selected Photos



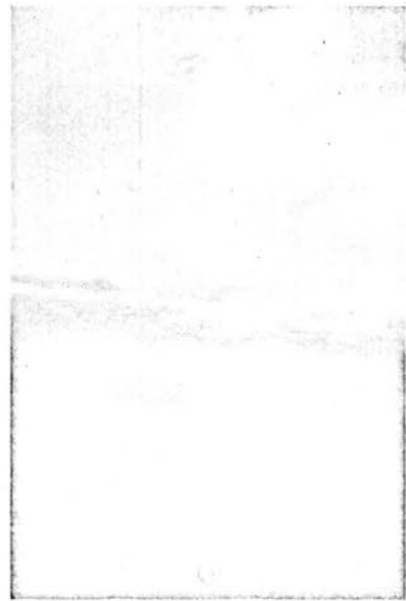
S-1500 Dissipating cell moving farther east; very little up air was found in the vicinity of this cell.



D-1700d Looking southwest from Sterling at the test case fifteen minutes after operation began.



S-1706b Test case from New Raymer looking southeast. Overcast obscuring all but the bottom of test case. Note part of New Raymer facility.



D-1720b Center portion of test case looking south. A great deal of icing and cirrus aloft.

30 July 1964
Selected Photos



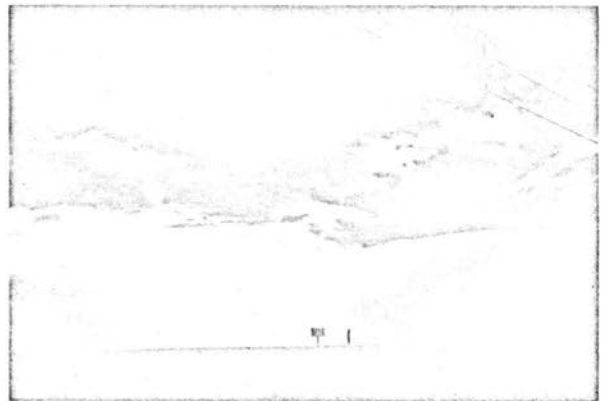
D-1732a, c Panoramic shot of entire test cell system. Test cell is on the right.



D-1742a, b Panoramic view of test case area. Test cell is on the right.



S-1755a General area from New Raymer looking north, generally overcast with many local showers.



S-1755b General area from New Raymer looking east.

30 July 1964
Selected Photos



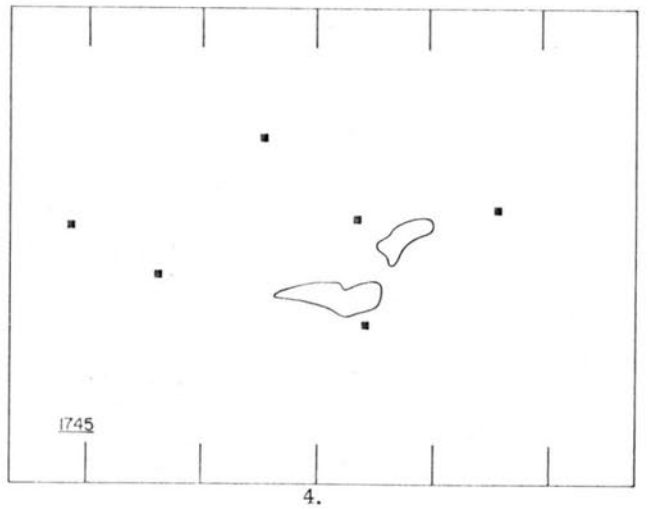
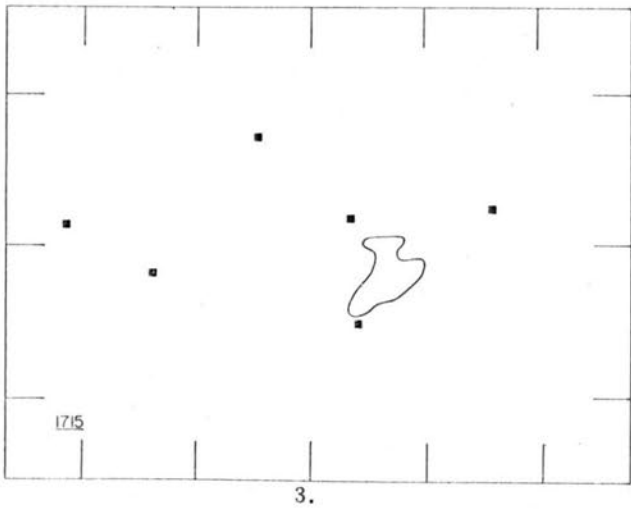
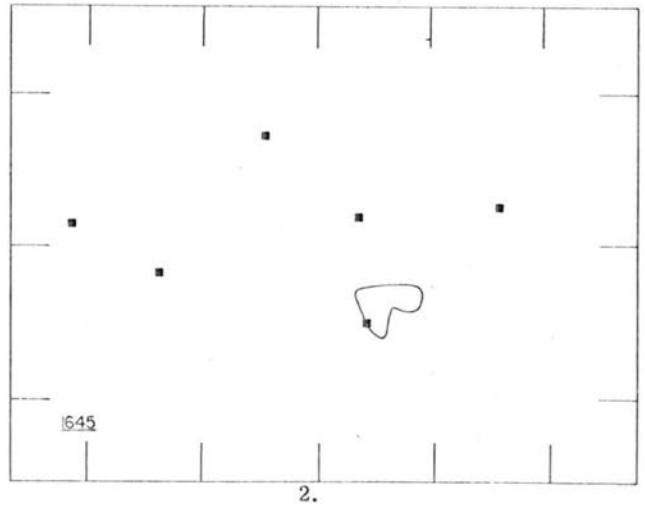
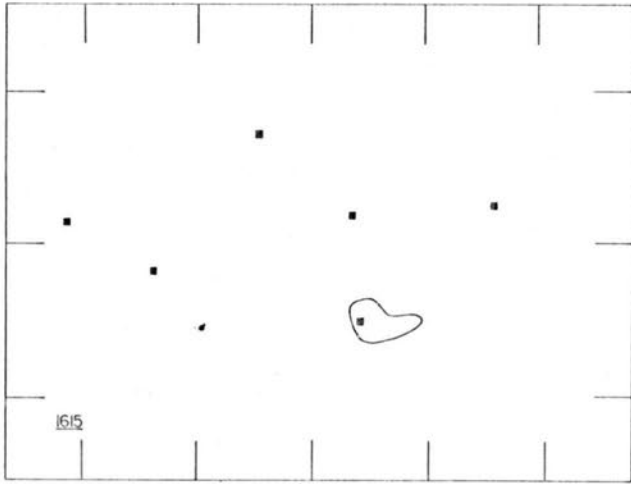
S-1755c General area from New Raymer
looking south.



S-1755d General area from New Raymer
looking west.

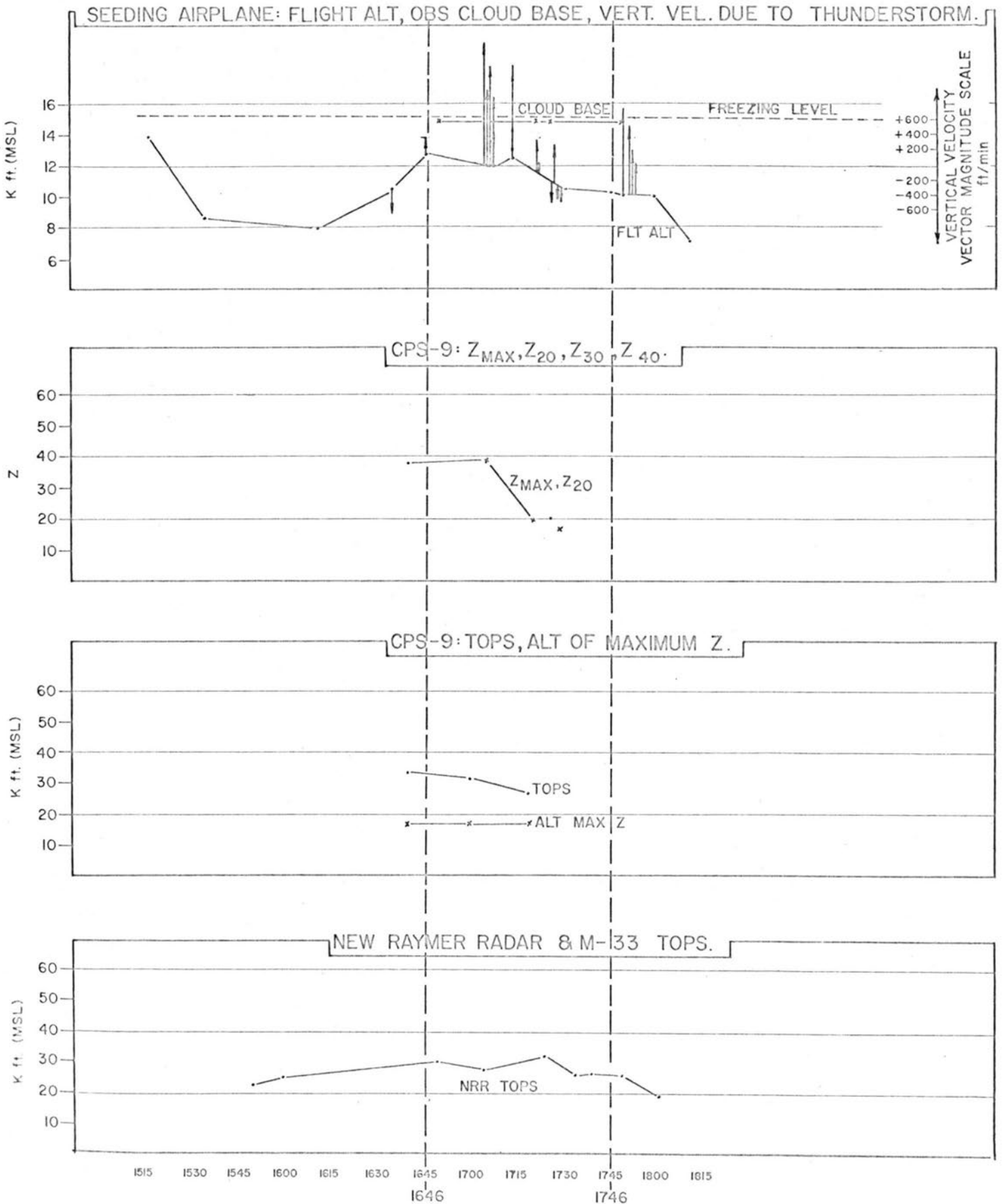
30 July 1964
Radar Echo Positions

Figure I



30 JULY-1964

FIGURE J



TEST CASE #1 OF 31 JULY 1964

Test Case Began 1417 MST, Ended 1502 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 14.0 gms/min. Equipment Used: Lohse Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	NA	0	NA	0	NA	0
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	NA	0	-125	4	NA	0

TEST CASE #3 OF 31 JULY 1964

Test Case Began 1600 MST, Ended 1641 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 7.7 gms/min. Equipment Used: Lohse Generator

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	31	1	NA	0	75	1
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	133	3	0	3	NA	0

SIGNIFICANT FEATURES

Northeastern Colorado remained in the warm sector east of a Pacific front extending from eastern Montana to northern Utah. Upper level air flow was from the southwest.

Since this was the last day of the 1964 season, it was decided to make this a definite "go" day. The operational plan for the day called for the first and third small cumuli to be seeded and the second was left unseeded. None of the field observers knew that the second cumulus was left unseeded. This system provided a method of comparison.

All men and equipment were in the field and functioning on this day. Only one of the three cases resulted in a detectable radar echo so the radars did not yield much data during this series of studies.

With three similar small cumuli to study, there were a few differences to be noted. The first cloud was seeded and produced no rain at the time, but an

echo developed over this area about one hour after seeding and produced rain on the ground.

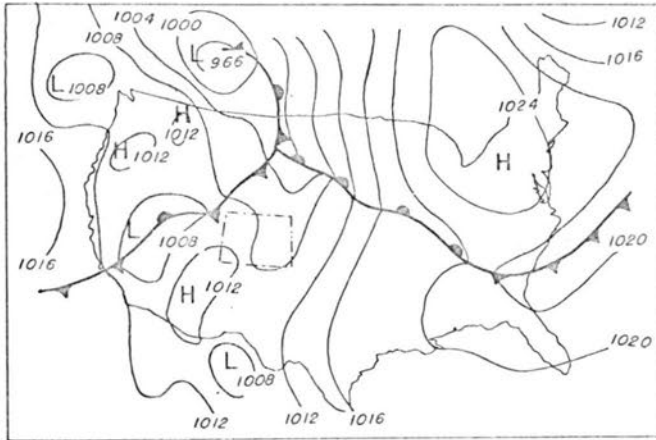
During cumulus growth study number two on this day, no seeding was accomplished. There were no noticeable changes in this small cell other than the fact that it dissipated in a very short time, similar to the other small cumuli in the area.

Cumulus number three was seeded and gave rain at the surface. Shortly after seeding began, this cell broke into three smaller cells and began to rain lightly. An hour after seeding began, the radar echo was considerably larger and the rain intensity was observed to increase.

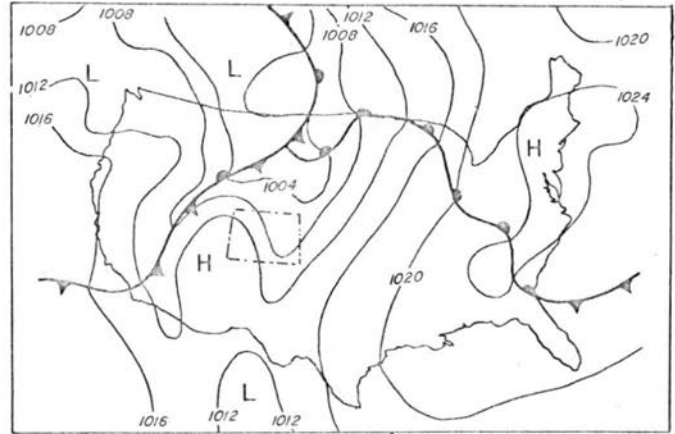
In many cases, precipitation was observed to reach the ground by the flight crews but was never reported by the cooperator network. Many times the reason the rain was not reported was that there were no cooperators living in the area.

31 July 1964
 U. S. Weather Bureau Synoptic Data

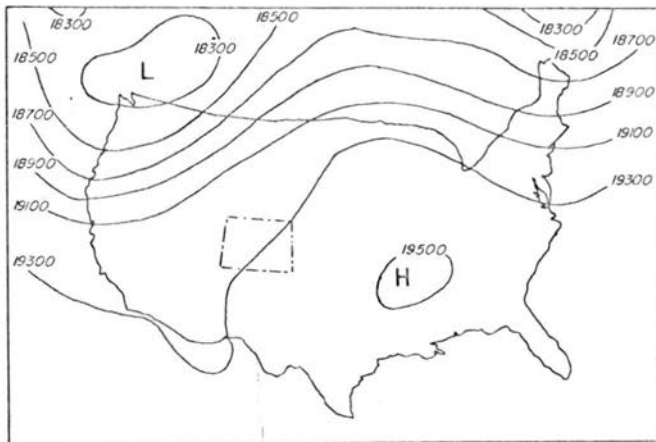
Figures A - F



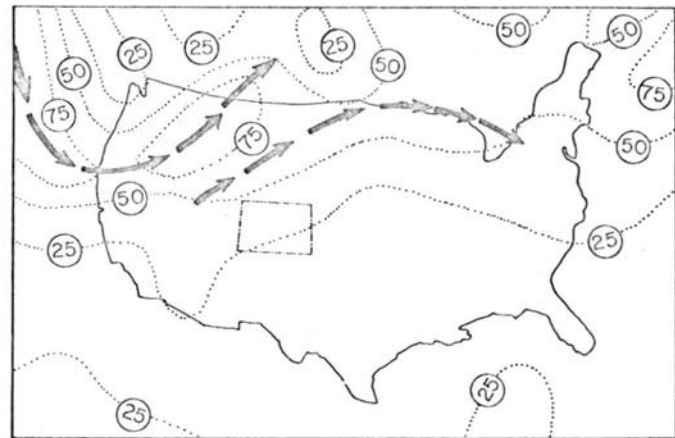
A. Surface Weather Map, 1100 MST (day of test case).



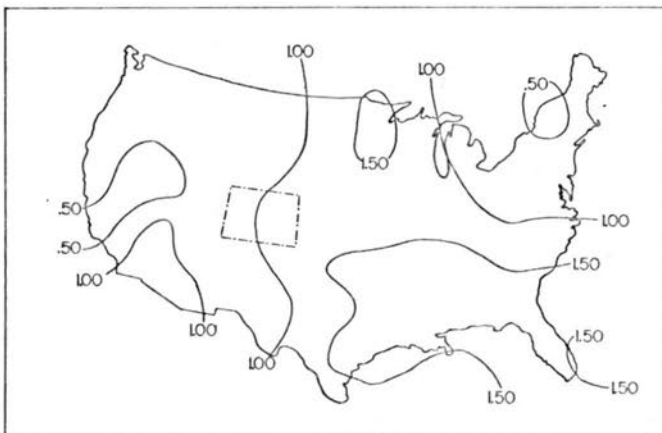
B. Surface Weather Map, 1100 MST (day following test case).



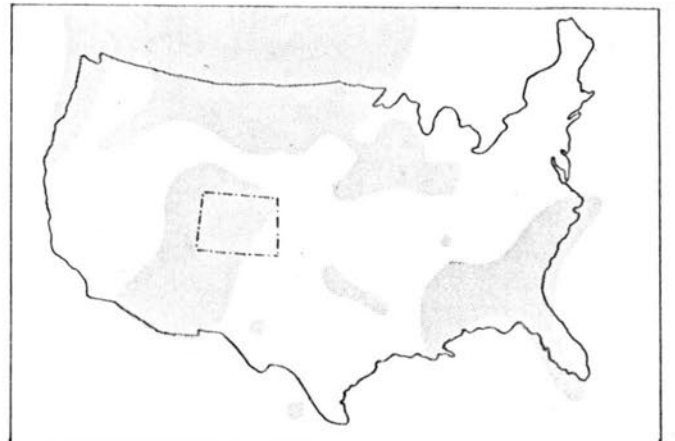
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



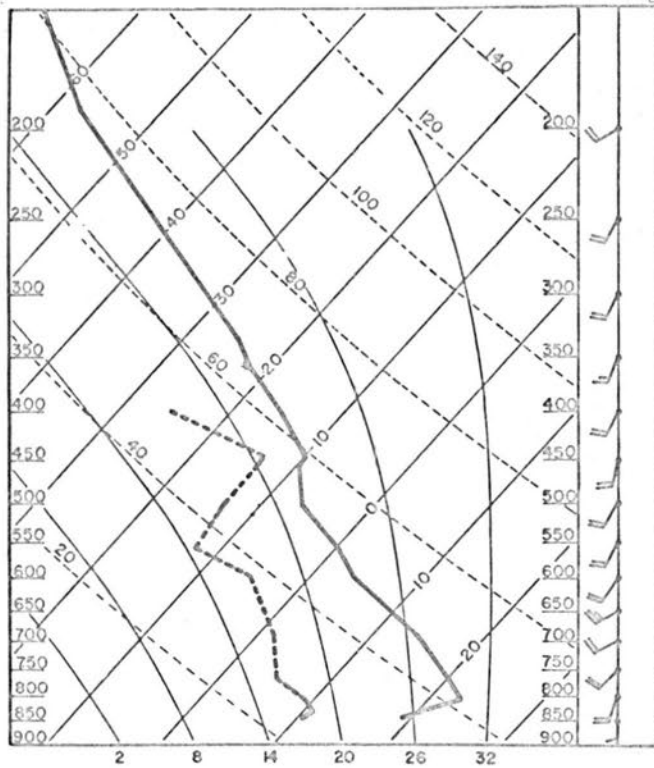
E. Precipitable Water, Inches, 1700 MST.



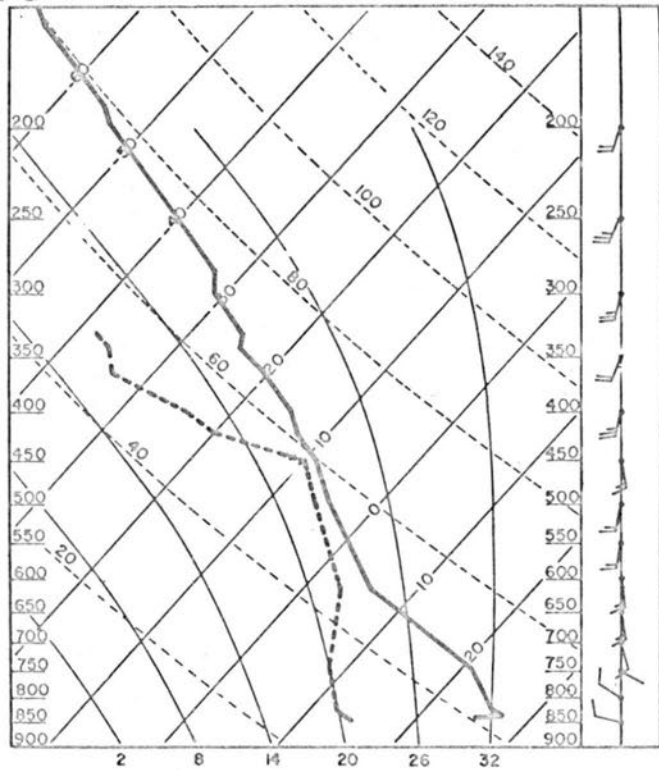
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

31 July 1964
Upper Air Soundings
Skew-T Diagrams

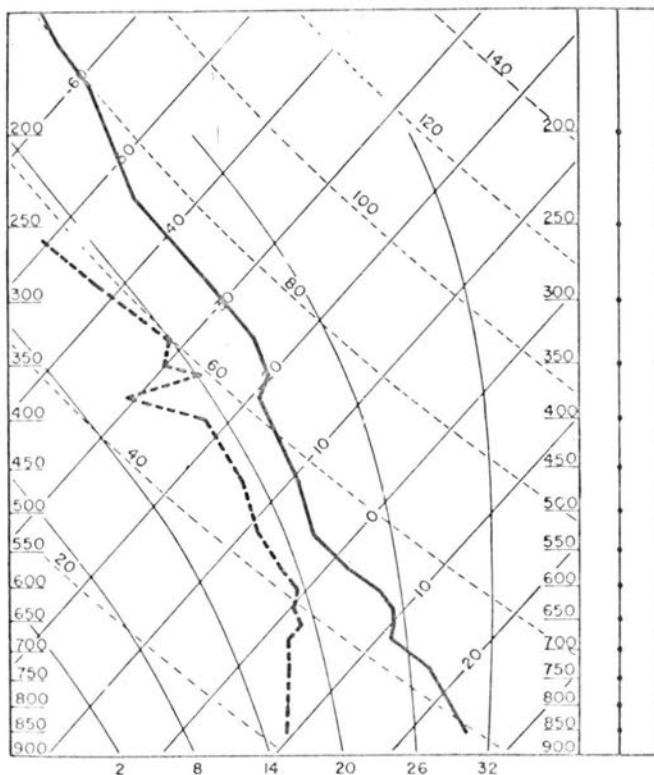
Figure G



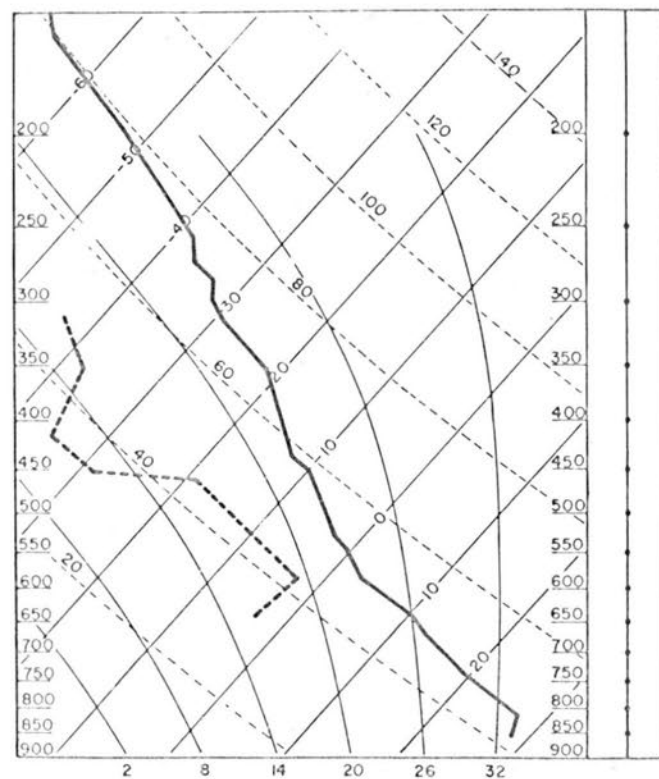
1. Denver, 0500 MST.



2. Denver, 1700 MST.

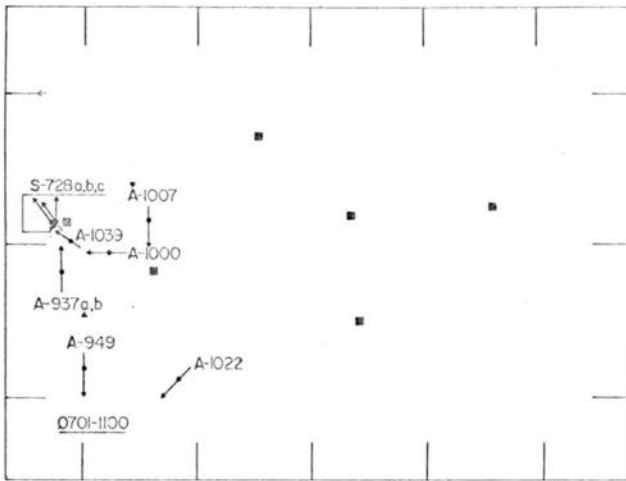


3. Fort Collins, 0830 MST.

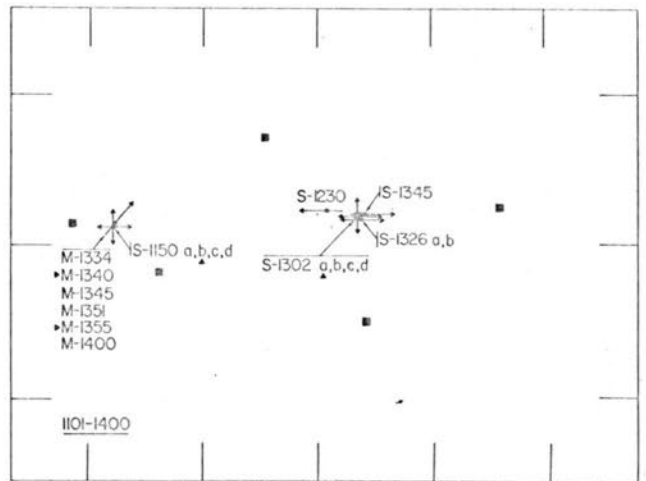


4. Fort Collins, 1500 MST.

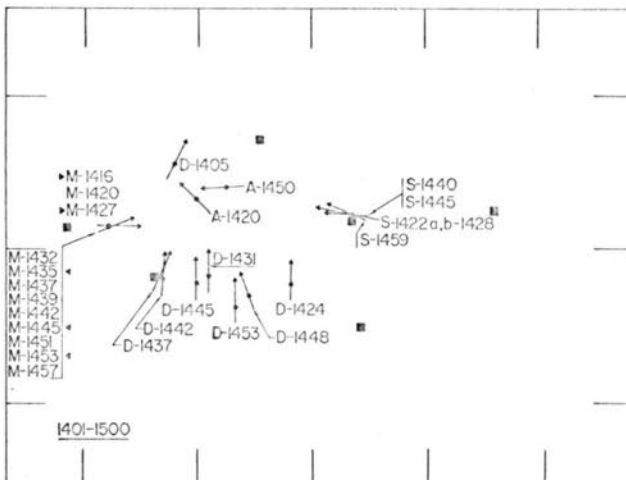
31 July 1964
 Photo Index
 Figure H



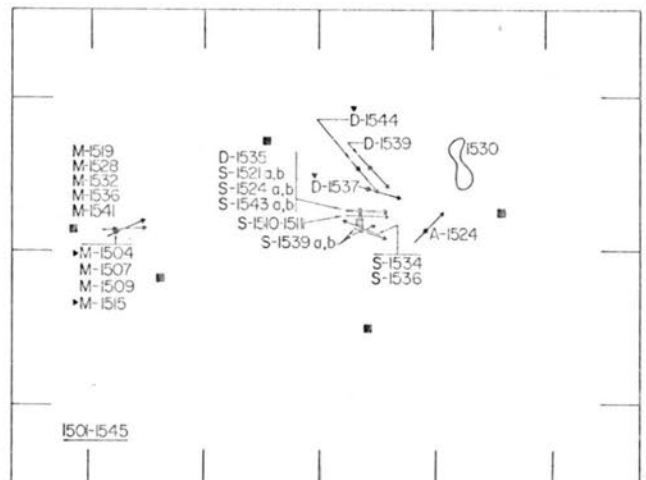
1.



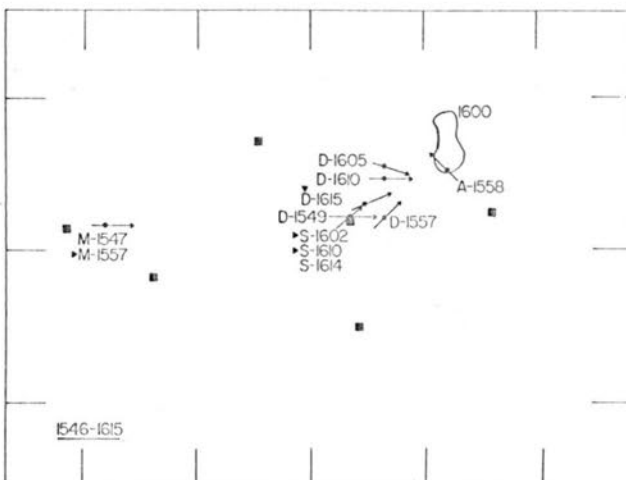
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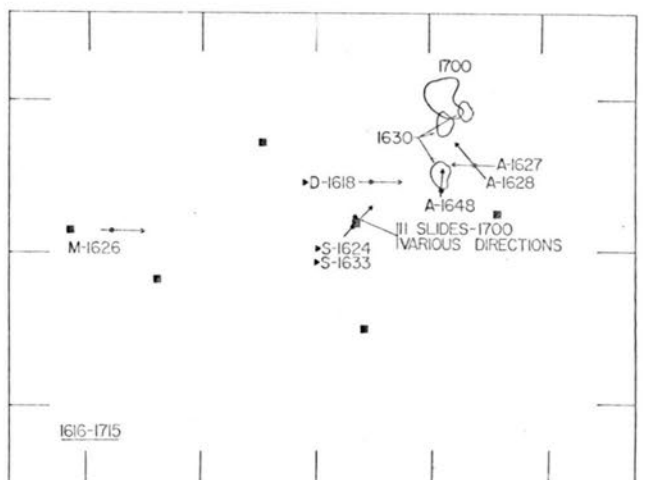
3.



4.



5.

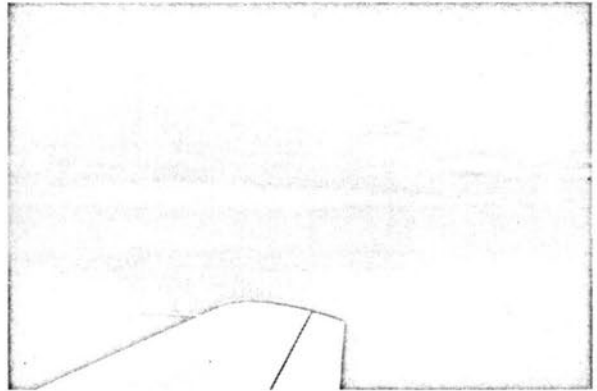


6.

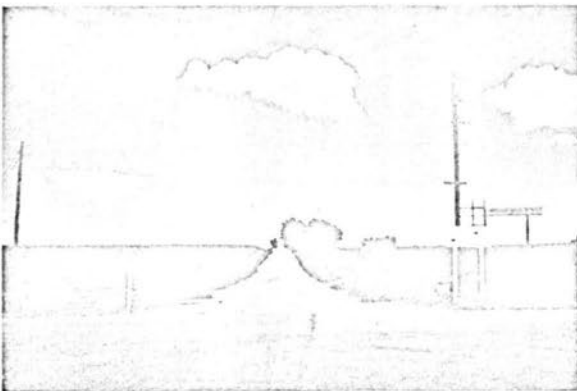
31 July 1964
Selected Photos



A-0937a Parallel to mountains, looking north, very little haze.



A-1007 Smoke layer over Greeley, estimated top 7,000 feet MSL. Relatively clear skies.



S-1150b Small cumulus starting to build north of M-33 site.



S-1302a West from New Raymer, scattered deck of small cumulus developing.



M-1340 Looking east-northeast from M-33 at test case #1 for the day.

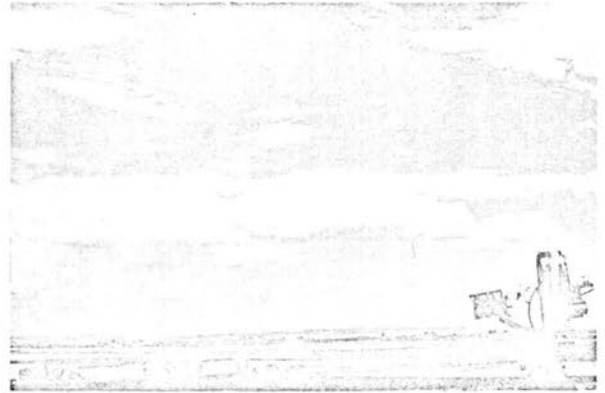


M-1355 Northeast from M-33 twenty-two minutes before operation began.

31 July 1964
Selected Photos



M-1416 Test case one minute before operation began. Note very limited growth.



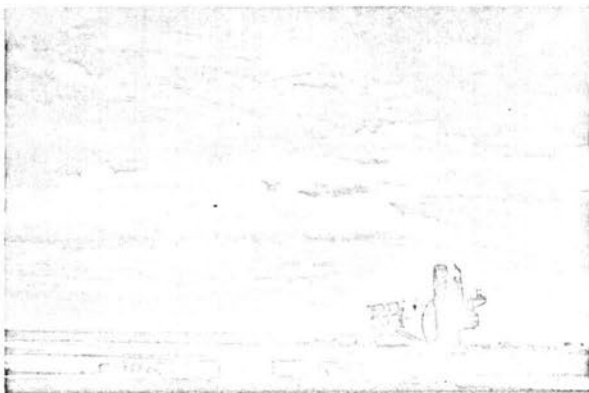
M-1427 Ten minutes after operation began and virtually no up air was found.



M-1435 Nineteen minutes after operation began.



M-1445 Twenty-nine minutes after operation began. Note moderate growth in the last two pictures.



M-1453 Thirty-seven minutes after operation began; clouds beginning to obscure test case #1.



M-1504 Forty-eight minutes after operation began; clouds completely obscuring the top of the test case.

31 July 1964
Selected Photos



M-1515 Fifty-nine minutes after operation began, thirteen minutes after it ended, test case completely obscured. Trace of precipitation fell.



D-1537 Test cell #2 thirteen minutes after operation began.



D-1544 Test cell #2 twenty minutes after operation began, no growth, no precipitation.



D-1557 Test cell #3 three minutes before operation began.



S-1602 Test cell #3 as observed from New Raymer.

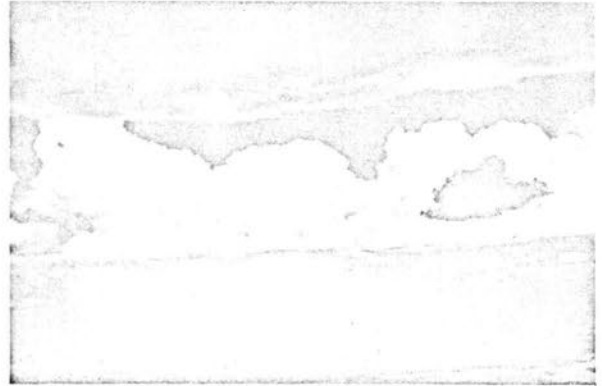


S-1610 Test cell #3 ten minutes after operation began.

31 July 1964
Selected Photos



D-1615 Test cell #3, bases extremely high about 13,800 feet MSL.



D-1618 Test cell #3, note light precipitation beginning to fall from the test case.



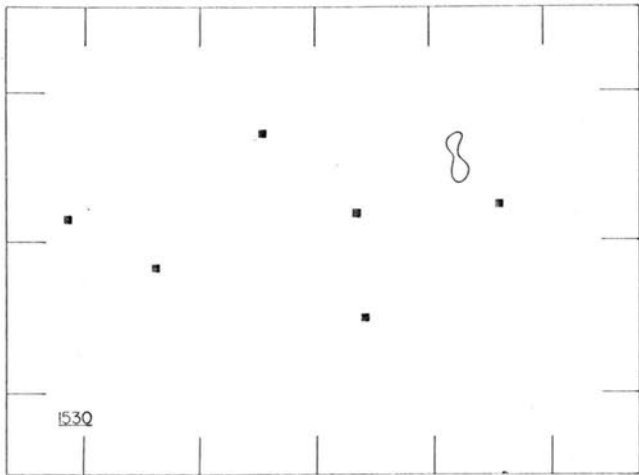
S-1624 Telephoto picture of the top of test case #3 from New Raymer.



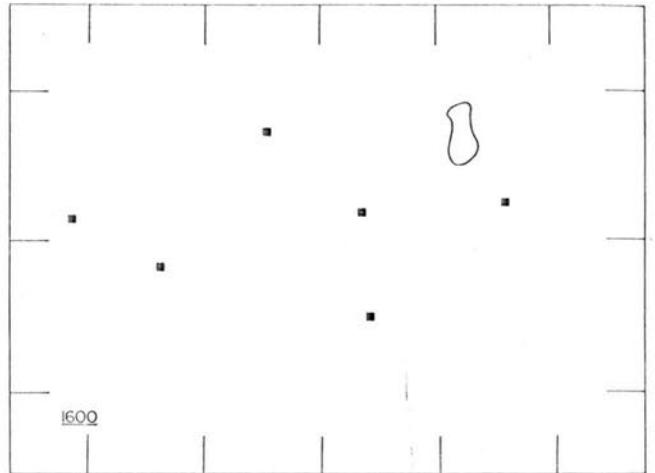
S-1633 Telephoto picture thirty-three minutes after operation began on test case #3. Note light icing, generally sharp edges.

31 July 1964
Radar Echo Positions

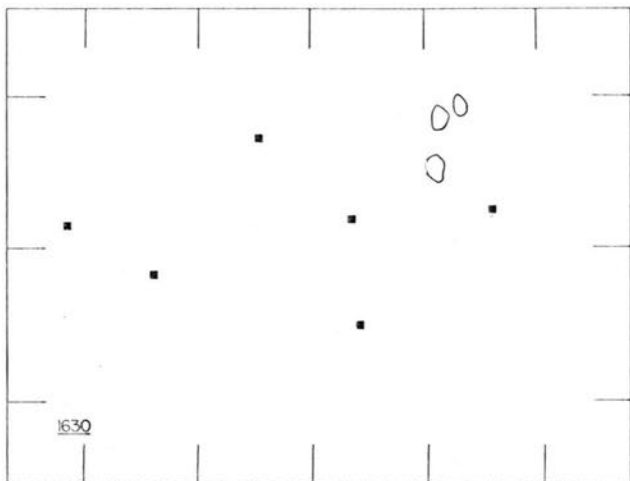
Figure I



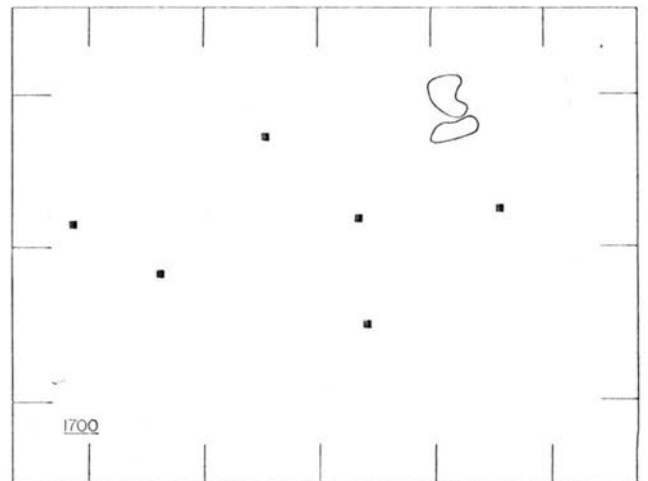
1.



2.

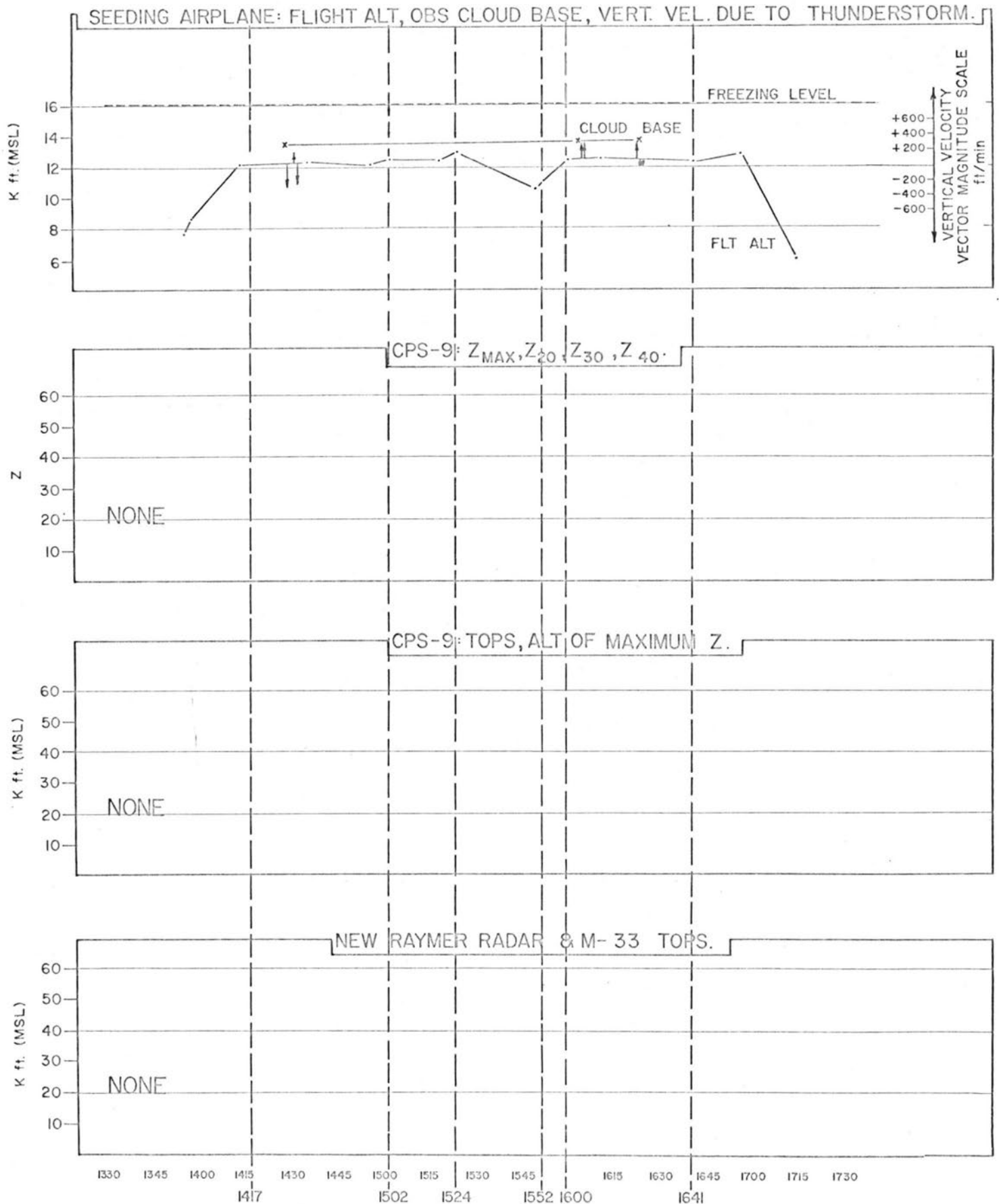


3.



4.

31 JULY -1964
FIGURE J



TEST CASE OF 15 JUNE 1963

Test Case Began 1536 MST, Ended 1603 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 8.3 gms/min. Equipment Used: Fuquay Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	2	1	1/2	1	NA	0
Maximum energy no., ft-lb/ft ²	1,575	1	31	1	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	31,000	1	25,000	1	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	54	1	NA	0	NA	0
Rainfall-volume, acre-feet	10.7		8.7		6.0	
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

SIGNIFICANT FEATURES

The surface weather map shows air motion from the northeast throughout the period of the test case with the cooler air behind the cold front extending from central Oklahoma into New Mexico. A 500 mb trough existed over southwestern Colorado and upper-air flow was from the southwest.

The New Raymer radar and the CPS-9 radar were functioning properly as were the field crew and the seeding airplane.

Not much information was obtained from visual observations since the cloud cover was fairly dense

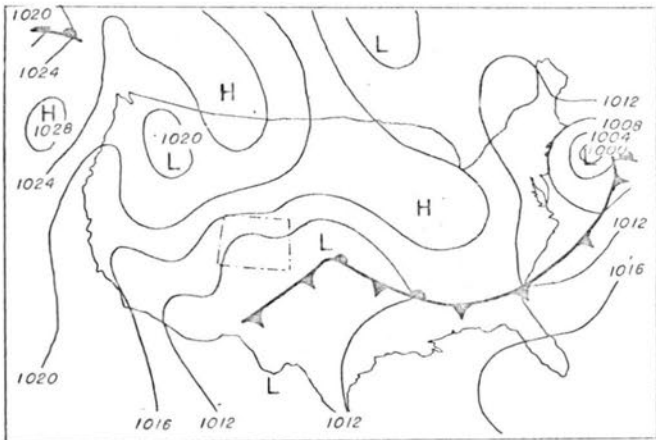
over the area. The number of photos of the test case were also limited since there was no observation airplane and the seeding aircraft was not able to take many pictures.

As can easily be seen from Figure J, this test case was started much too late since the echo had quite obviously started to dissipate rapidly.

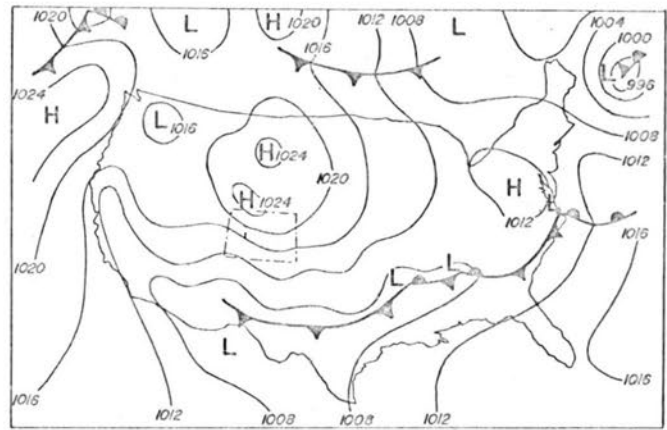
From the photos, one can see that there was a general overcast situation over most of the area. There was quite a lot of rain over the area and not very much hail.

15 June 1963
 U. S. Weather Bureau Synoptic Data

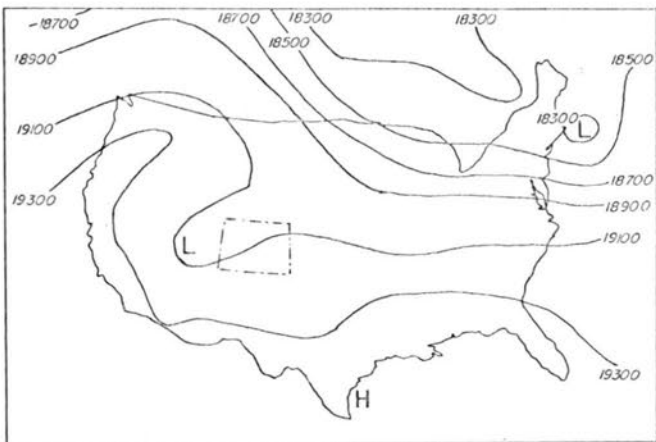
Figures A - F



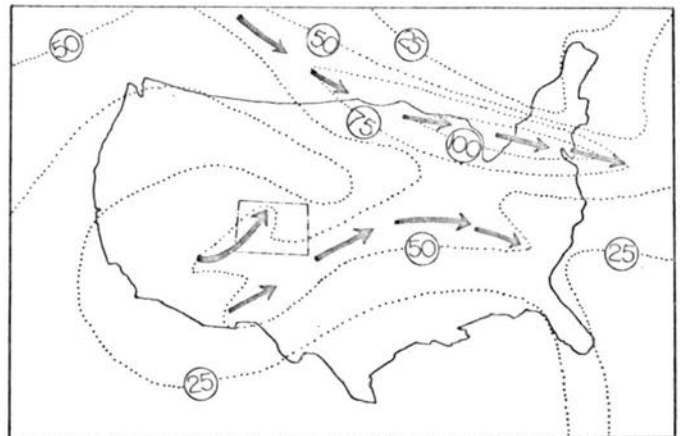
A. Surface Weather Map, 1100 MST (day of test case).



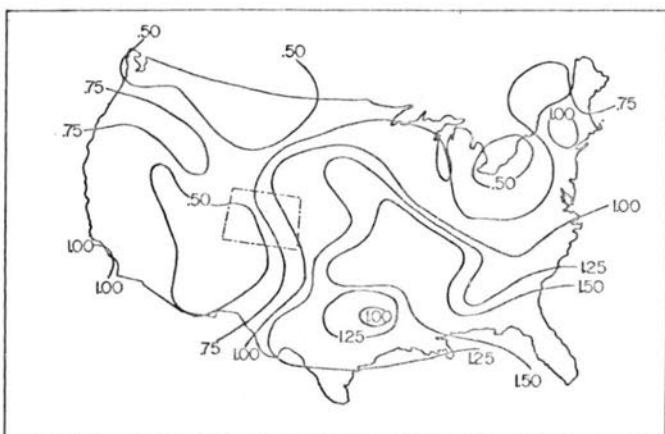
B. Surface Weather Map, 1100 MST (day following test case).



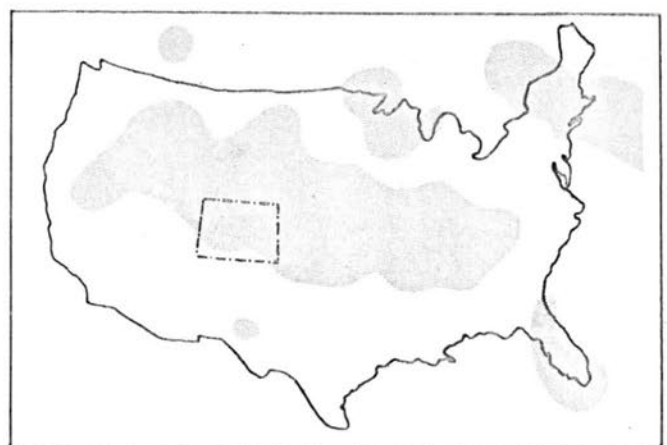
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



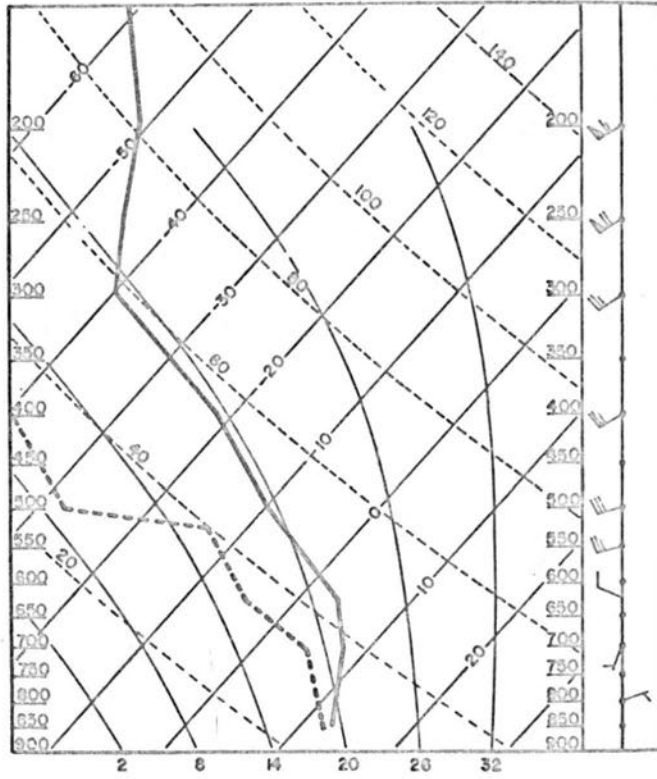
E. Precipitable Water, Inches, 1700 MST.



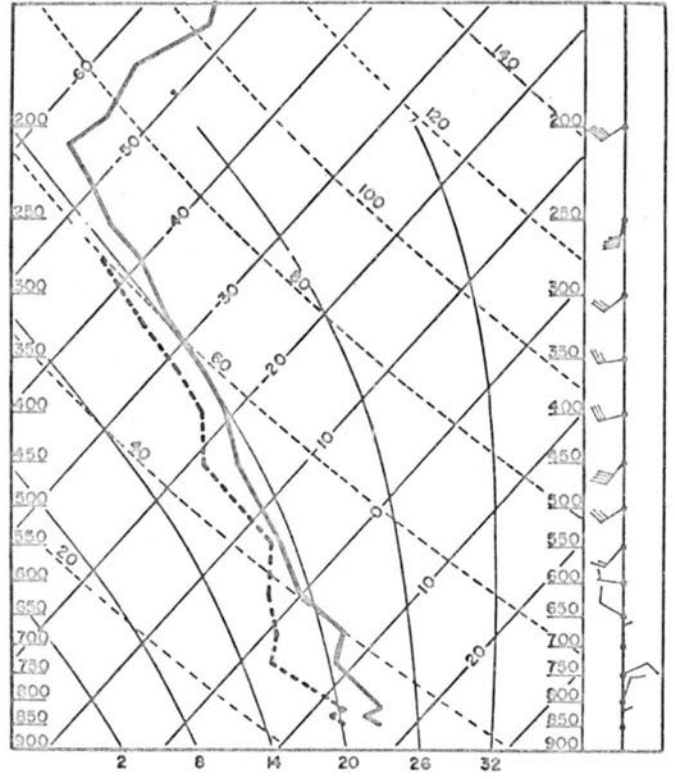
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

15 June 1963
Upper Air Soundings
Skew-T Diagrams

Figure G



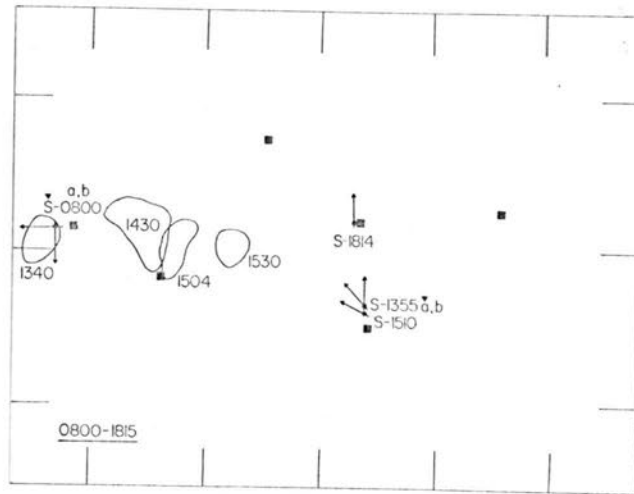
1. Denver, 0500 MST.



2. Denver, 1700 MST.

15 June 1963
Photo Index

Figure H

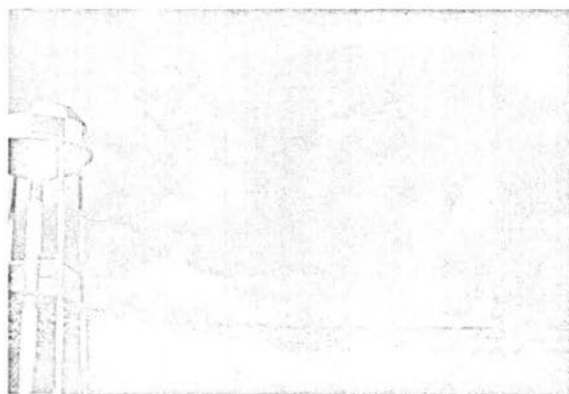


1.

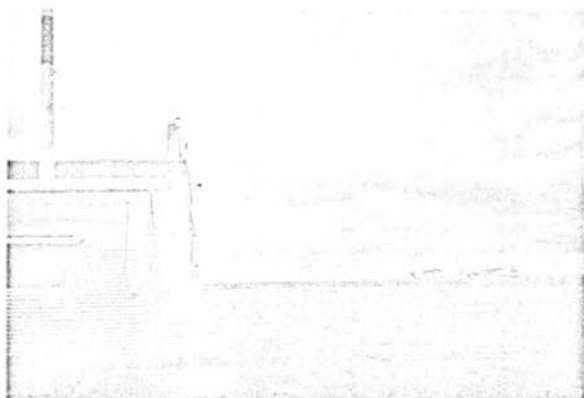
15 June 1963
Selected Photos



S-0800a Looking south from Fort Collins,
early morning clouds.



S-0800b Looking west from Fort Collins.
Clouds over mountains in the early
morning.



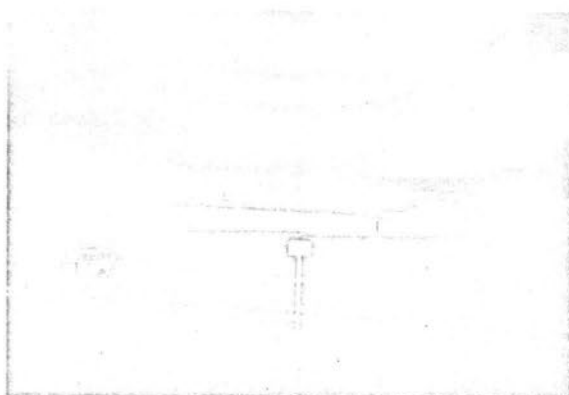
S-1355a Looking north from Fort Morgan at
the general cloud cover.



S-1355b Looking northwest from Fort Morgan
at the general cloud cover.



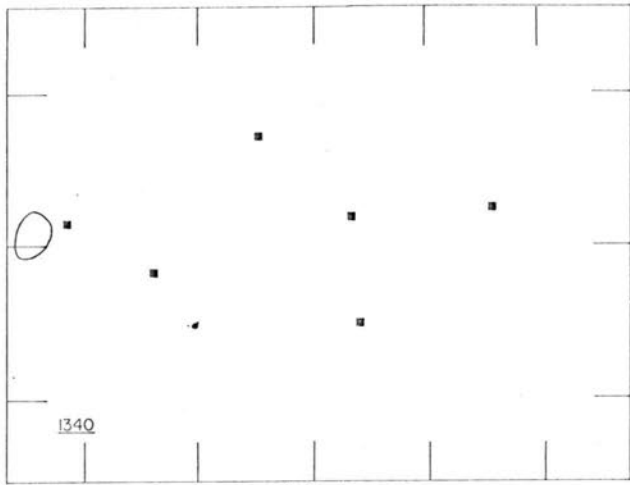
S-1510 General cloud cover west of Fort
Morgan twenty minutes before test
case began.



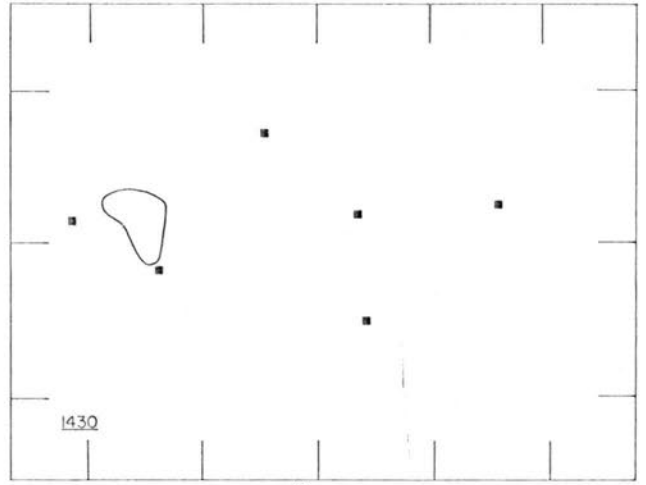
S-1814 Looking north from New Raymer
site. General low cloud cover.

15 June 1963
Radar Echo Positions

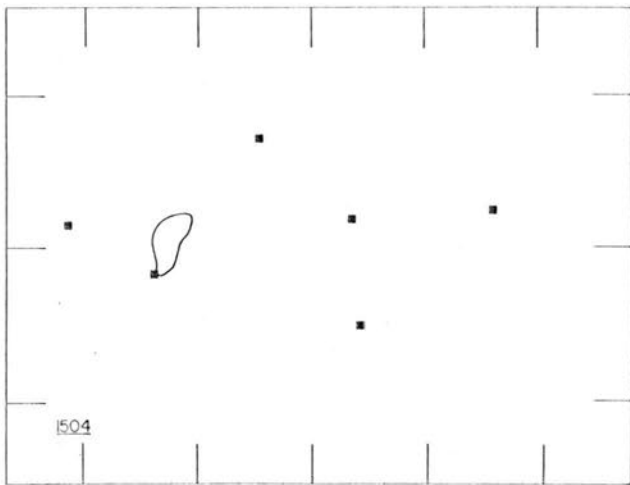
Figure I



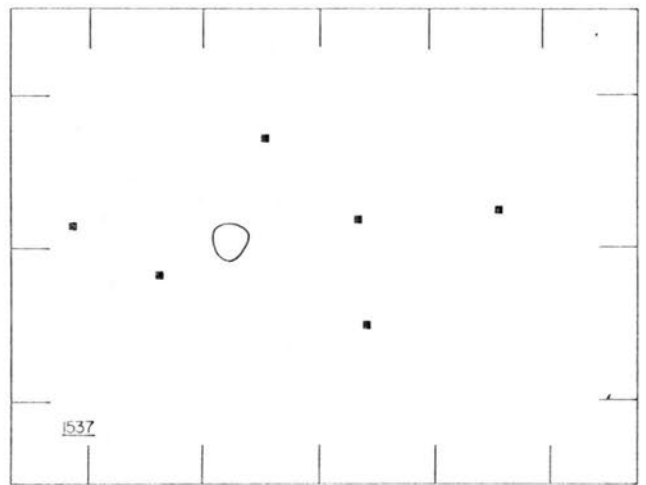
1.



2.



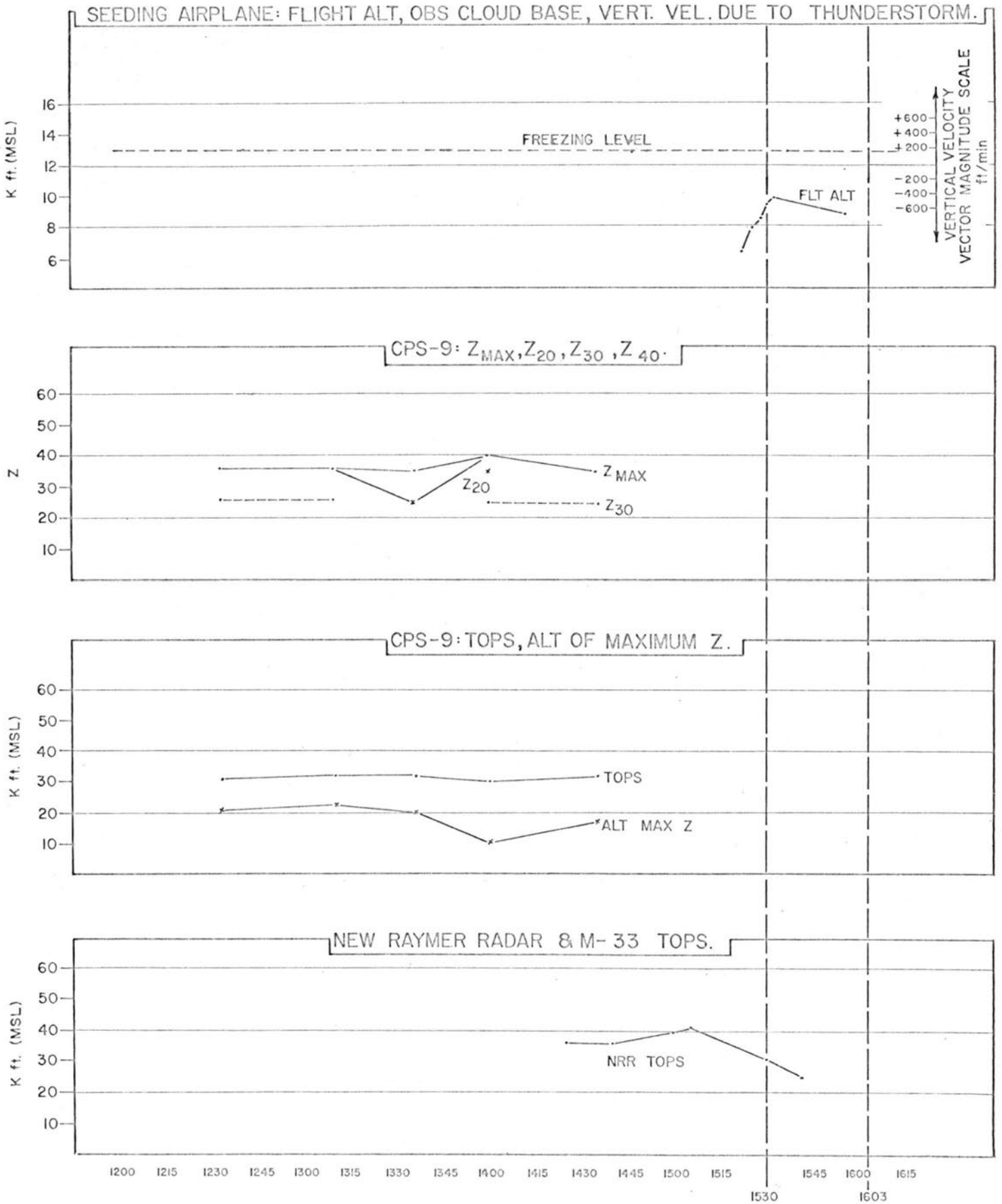
3.



4.

15 JUNE-1963

FIGURE J



TEST CASE OF 11 JULY 1963

Test Case Began 1353 MST, Ended 1434 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 8.3 gms/min. Equipment Used: Fuquay Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/2	1	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	440	1	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	42,200	1	37,000	1	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	NA	0	577*	2	674*	1
Rainfall-volume, acre-feet	8.9		3.9		0.6	
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

*Attenuation

SIGNIFICANT FEATURES

A complex frontal system occurred in northeastern Colorado on this date, with upper air flow from the southwest and the jet stream extending from Utah into the eastern Dakotas.

The seeding operation began at a time when hail was observed falling from the test cell. At the beginning of the seeding, strong updrafts were observed and associated cloud cover included a roll cloud in advance of the thunderstorm cell. The updrafts decreased in a period of approximately 15 minutes,

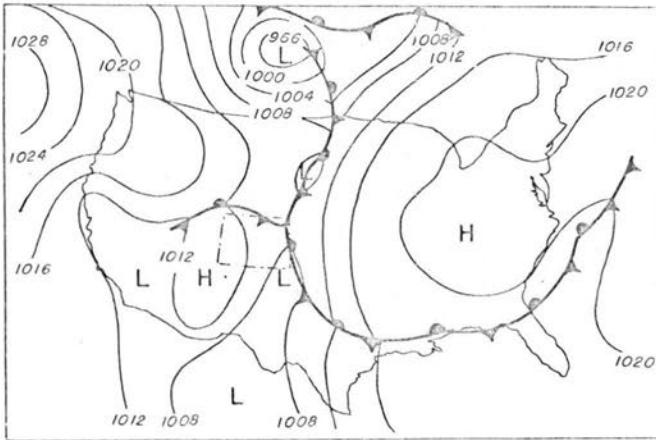
and the roll cloud disappeared at the same time.

The CPS-9 and the M-33 radars were not able to obtain any information on this test case. There was no observation plane so the number of photos is very limited. There was very little visual data.

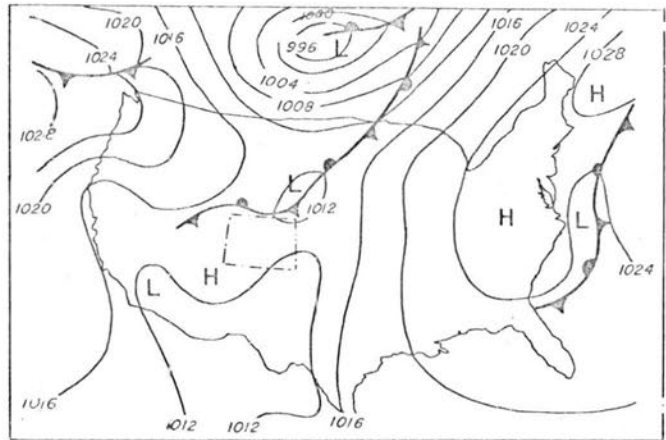
The test case evolved from a squall line situation and appeared to grow considerably after seeding took place. The test cell produced light rain over the area and no hail was observed.

11 July 1963
 U. S. Weather Bureau Synoptic Data

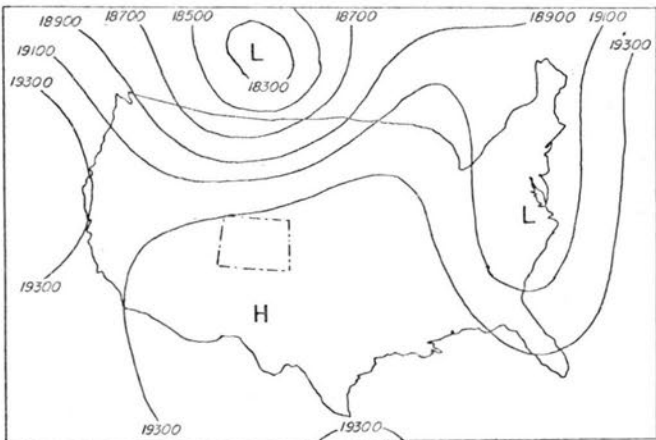
Figures A - F



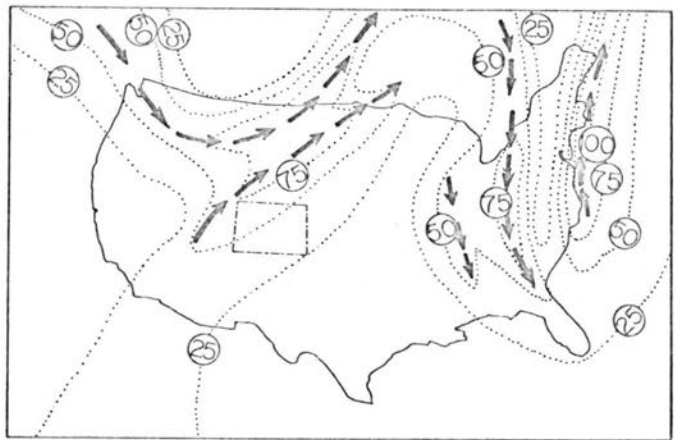
A. Surface Weather Map, 1100 MST (day of test case).



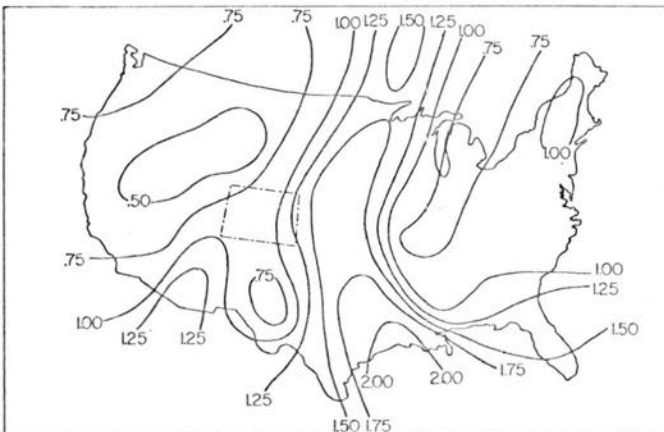
B. Surface Weather Map, 1100 MST (day following test case).



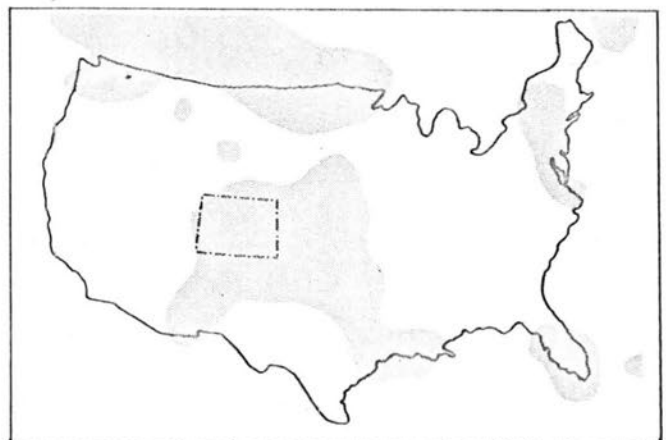
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



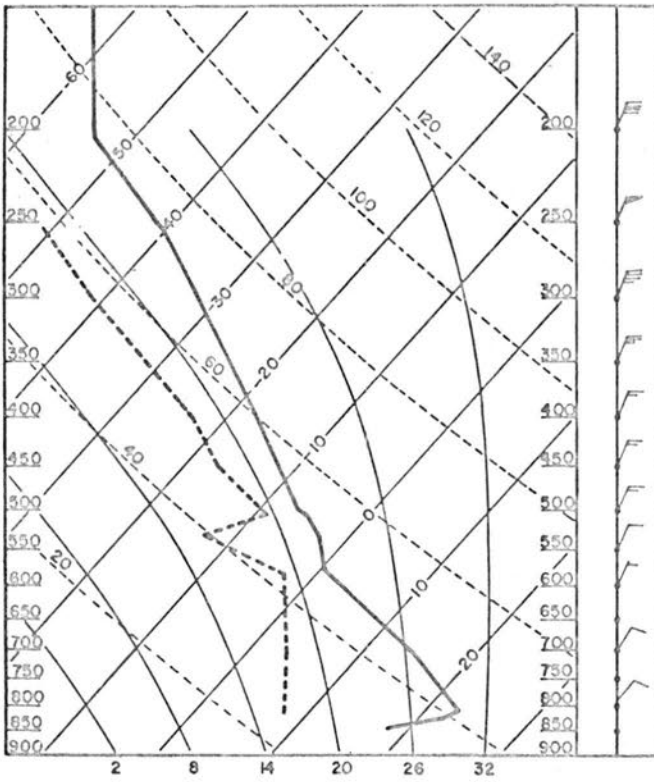
E. Precipitable Water, Inches, 1700 MST.



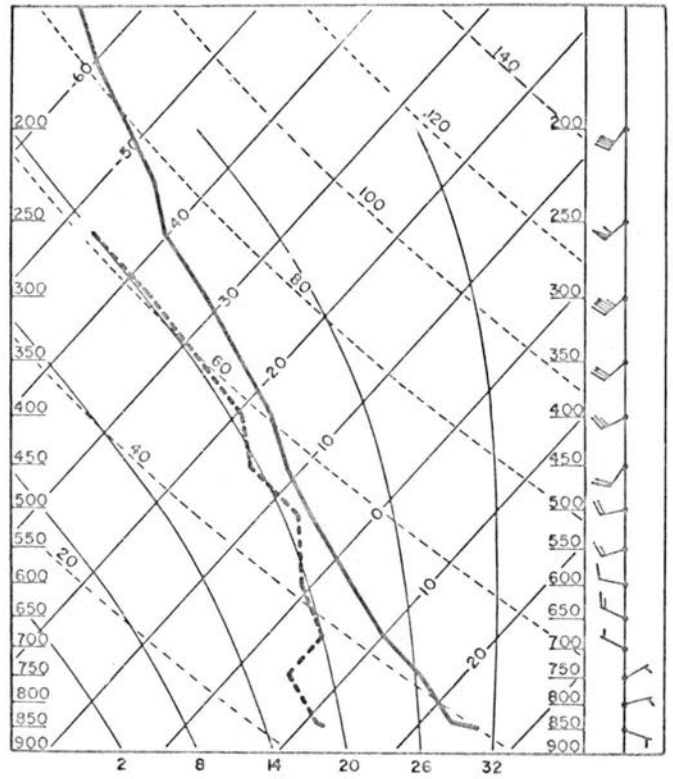
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

11 July 1963
Upper Air Soundings
Skew-T Diagrams

Figure G



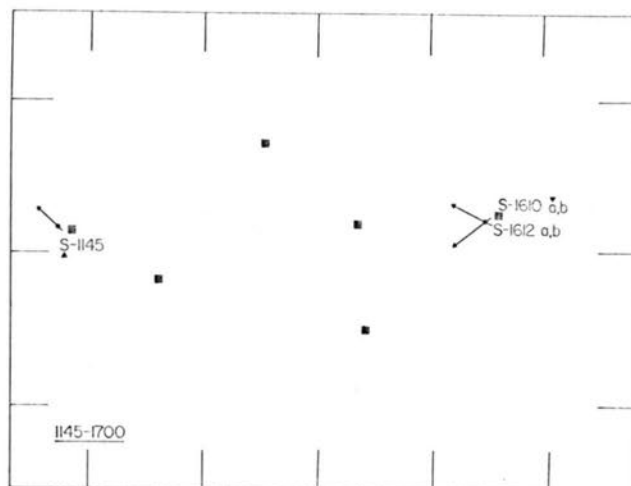
1. Denver, 0500 MST.



2. Denver, 1700 MST.

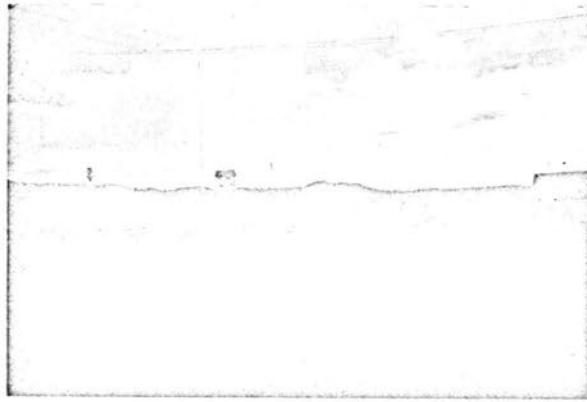
11 July 1963
Photo Index

Figure H



1.

11 July 1963
Selected Photos



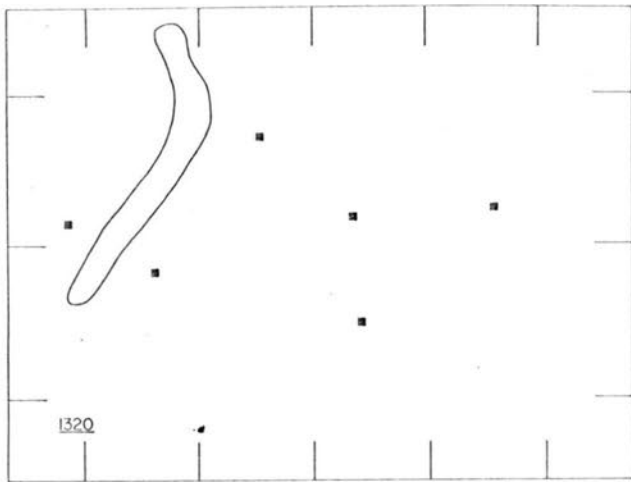
S-1145 Looking northwest from Fort Collins.
General cloud cover.



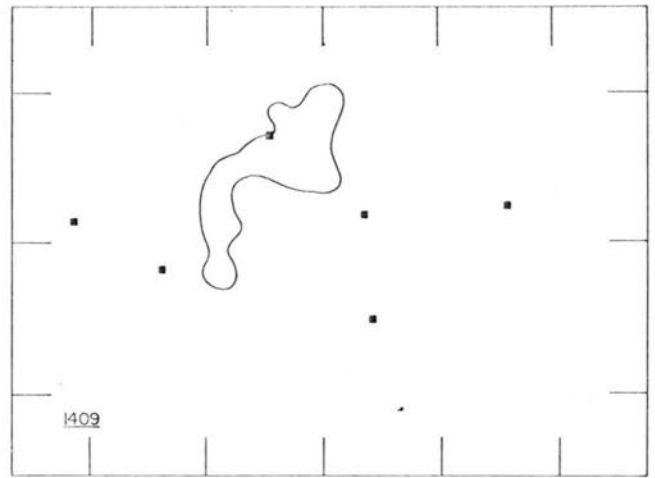
S-1610a Looking southwest from Sterling.
General cloud cover.

11 July 1963
Radar Echo Positions

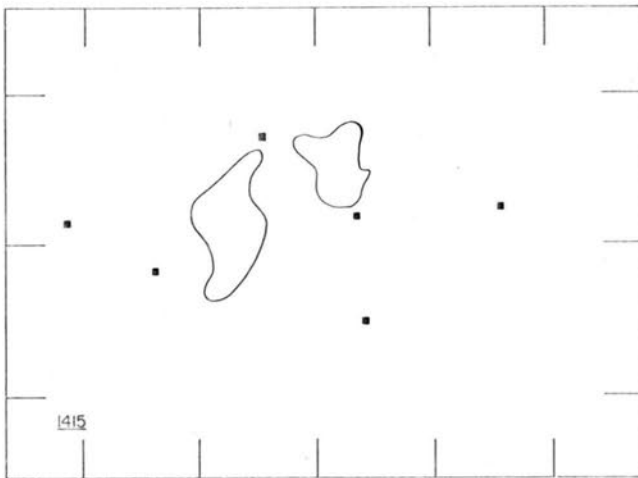
Figure I



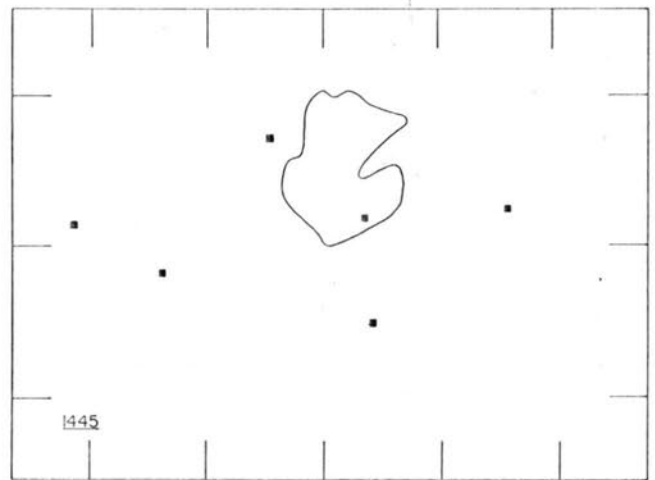
1.



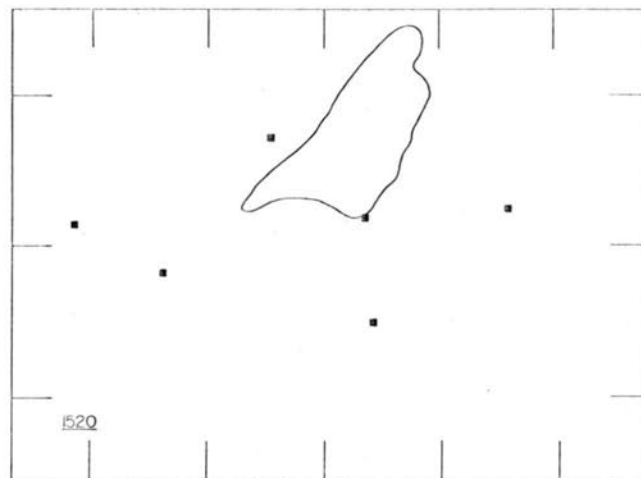
2.



3.

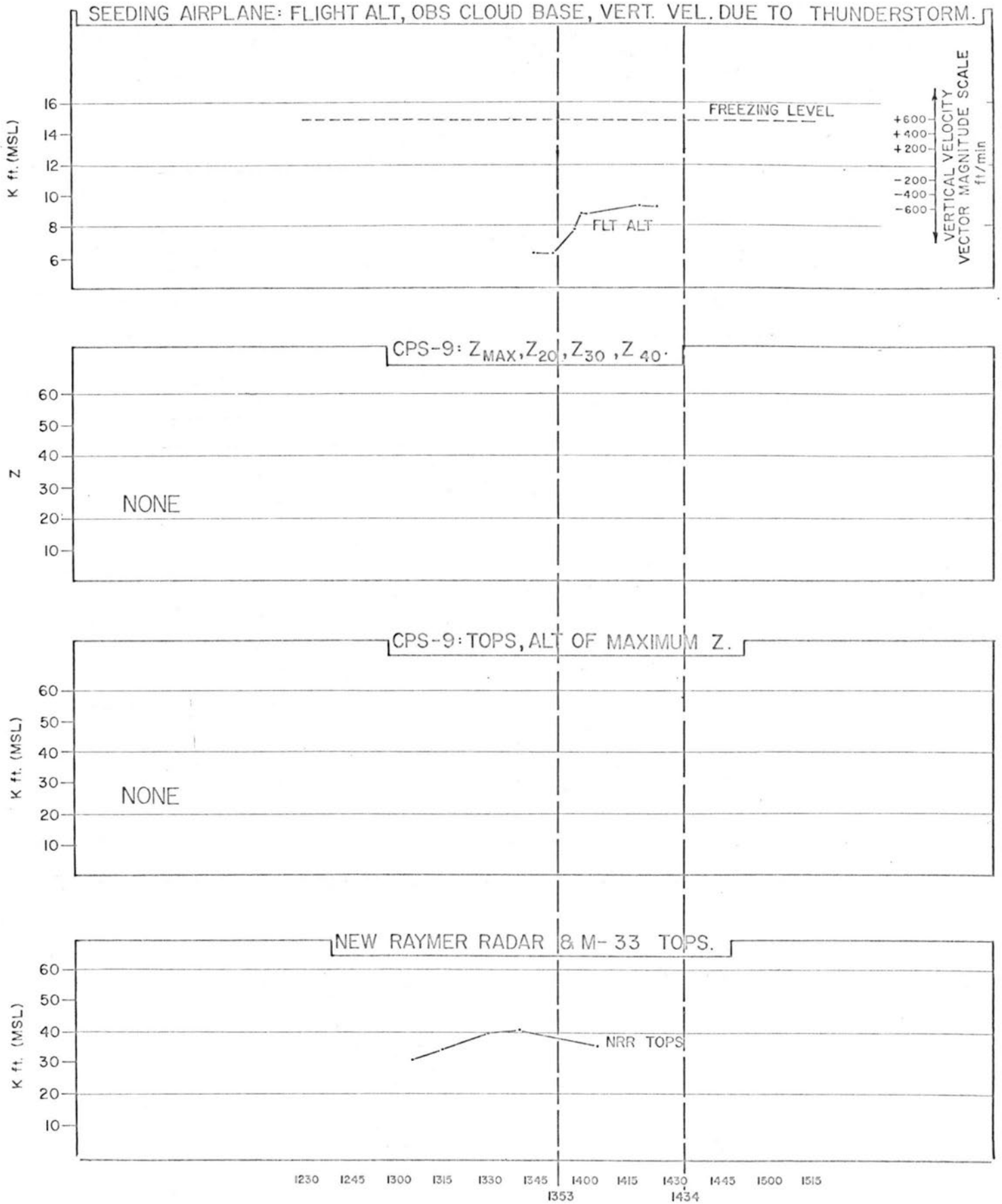


4.



5.

11 JULY-1963
FIGURE J



TEST CASE OF 12 JULY 1963

Test Case Began 1629 MST, Ended 1746 MST
 Seeded: YES Material Used: Ag I
 Rate of Seeding: 8.3 gms/min. Equipment Used: Fuquay Generator

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/4	1	1/2	1	NA	0
Maximum energy no., ft-lb/ft ²	31	1	9	1	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	20,000	1	NA	0	NA	0
Radar tops K-ft MSL, NRR	19,500	1	19,500	1	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	302*	1	357*	2	NA	0
Rainfall-volume, acre-feet	12.2		3.1		NA	0
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

*Attenuation

SIGNIFICANT FEATURES

A cold front passed through northeastern Colorado, and the test case selected was one of the clouds behind the cold front rather than one of the cells associated with the front itself. Upper level flow was from the west with the jet stream extending from southwestern Colorado into north-central Kansas.

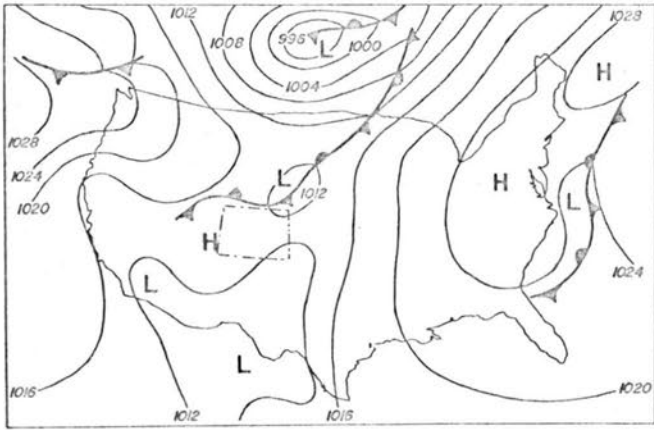
The visual indications from this test were for a dissipation of the cloud system concurrently with

the time of seeding. At the same time the seeding was going on, strong convection was continuing in connection with the main line of thunderstorms associated with the leading edge of the cold front passing through northeastern Colorado.

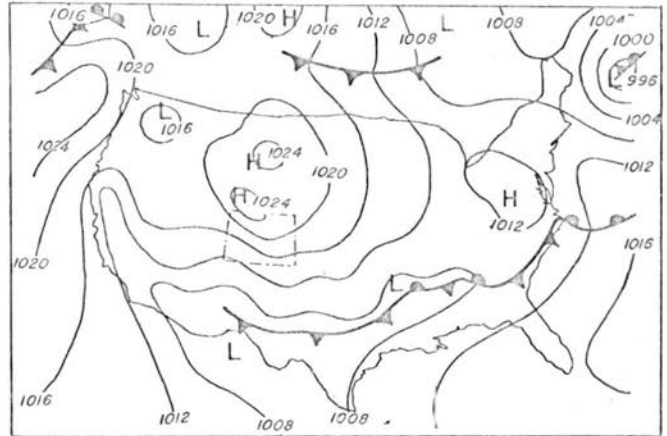
All radar data was very poor on this test case since the cell began dissipating shortly after the test case began. The photographic data is also limited since there were quite a number of clouds in the area during the test case period.

12 July 1963
 U.S. Weather Bureau Synoptic Data

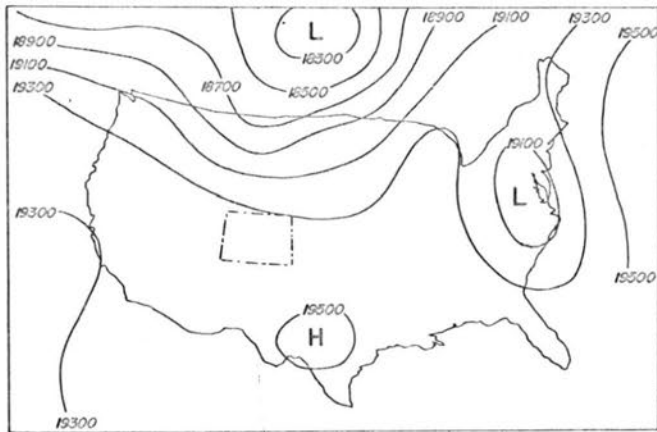
Figures A - F



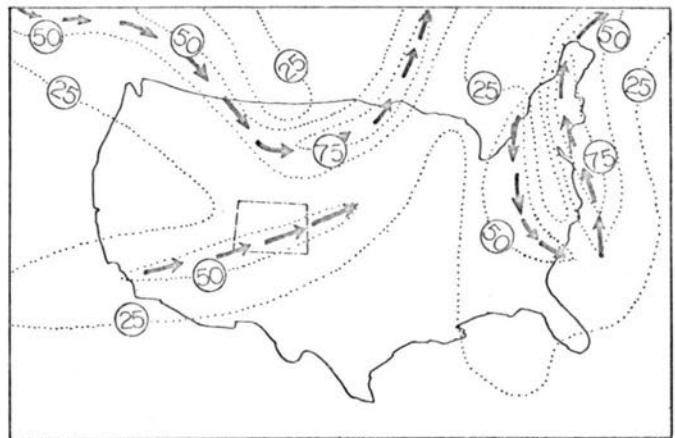
A. Surface Weather Map, 1100 MST (day of test case).



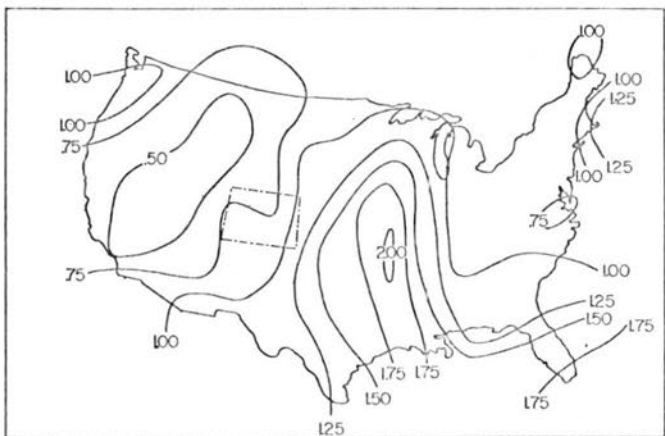
B. Surface Weather Map, 1100 MST (day following test case).



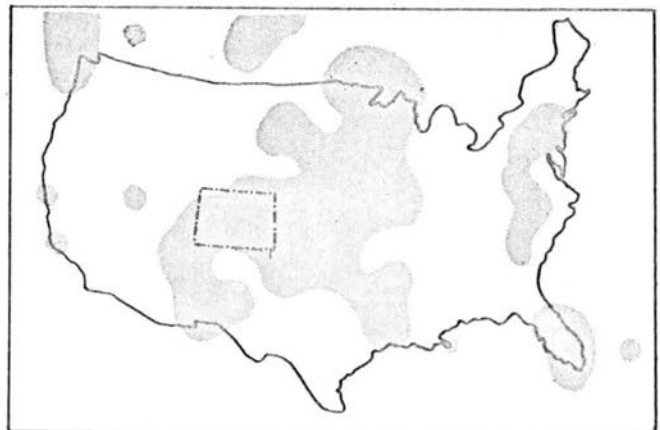
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



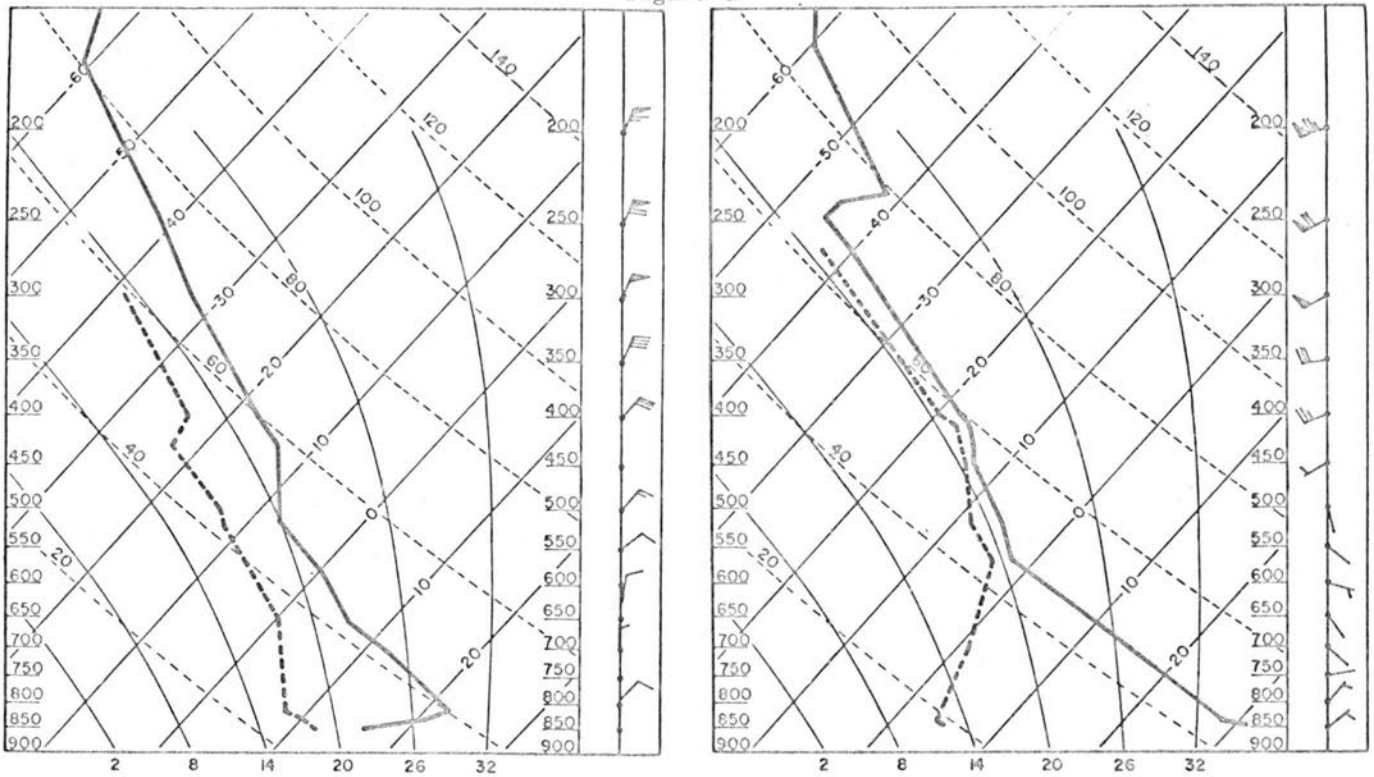
E. Precipitable Water, Inches, 1700 MST.



F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

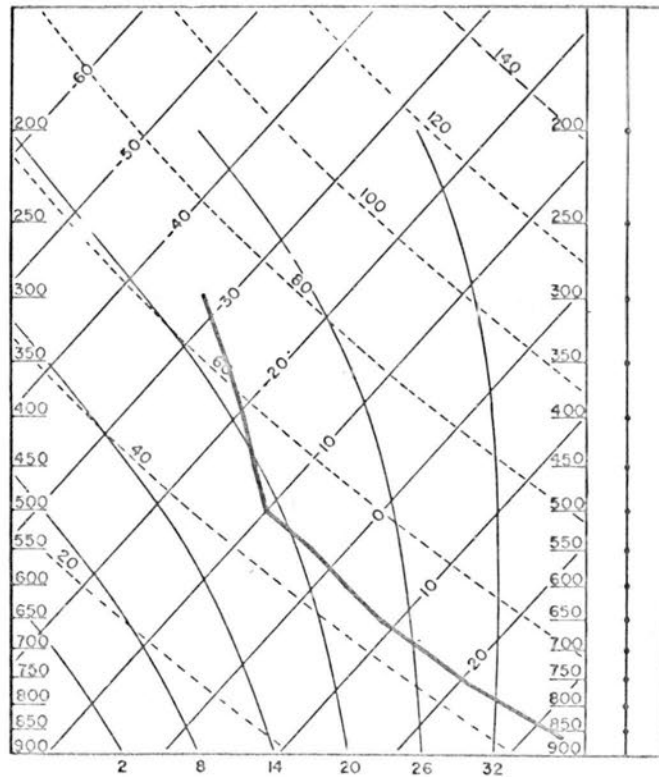
12 July 1963
Upper Air Soundings
Skew-T Diagrams

Figure G



1. Denver, 0500 MST.

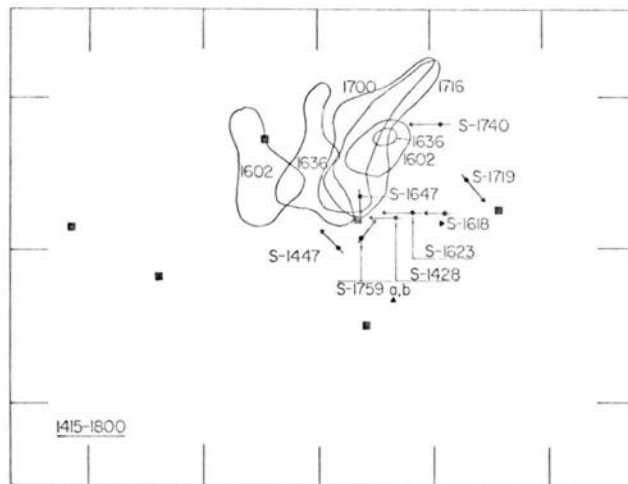
2. Denver, 1700 MST.



3. Fort Collins, 0930 MST.

12 July 1963
Photo Index

Figure H



12 July 1963
Selected Photos



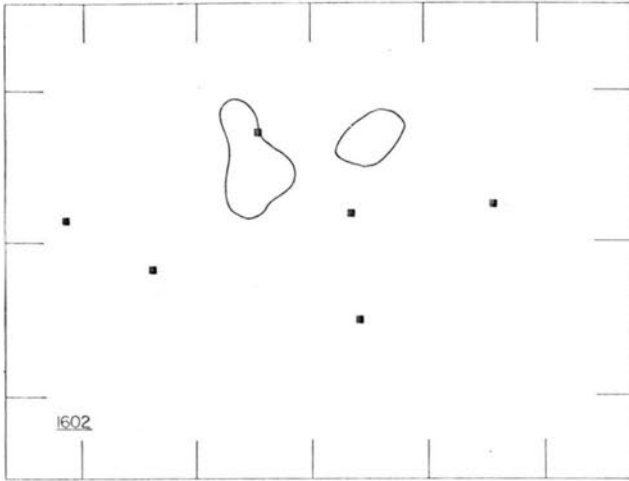
S-1618 Looking west along the south edge of the test case.



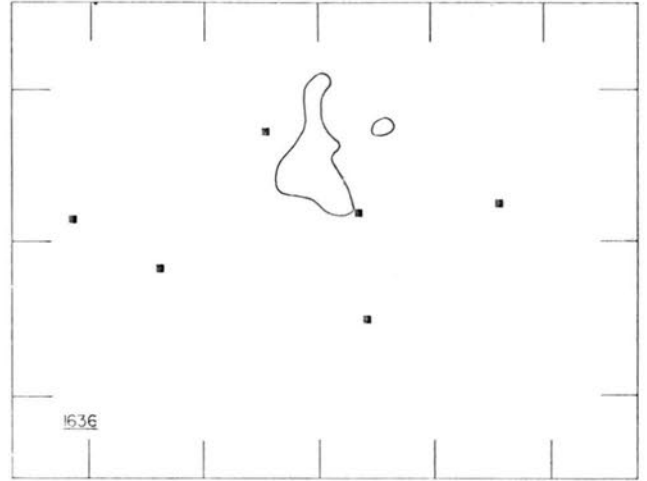
S-1759a Remains of seeded test case thirteen minutes after end of seeding.

12 July 1963
Radar Echo Positions

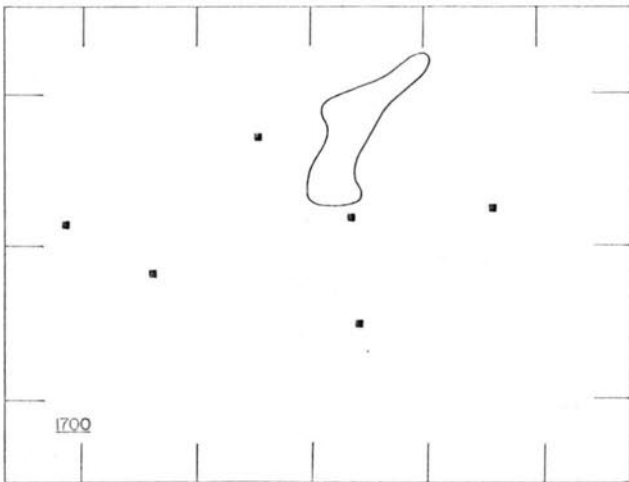
Figure I



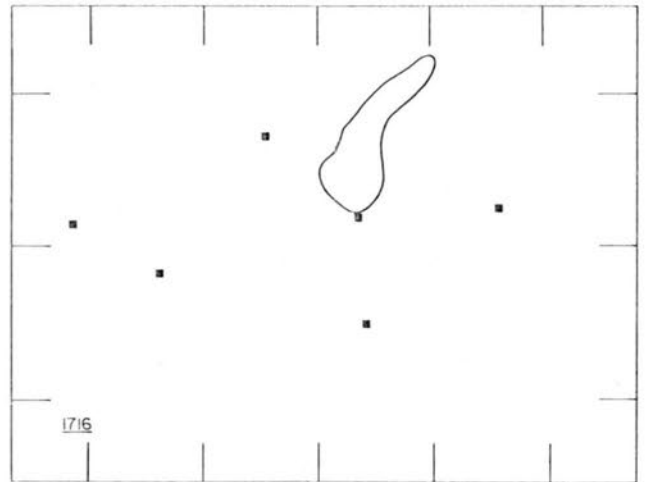
1.



2.



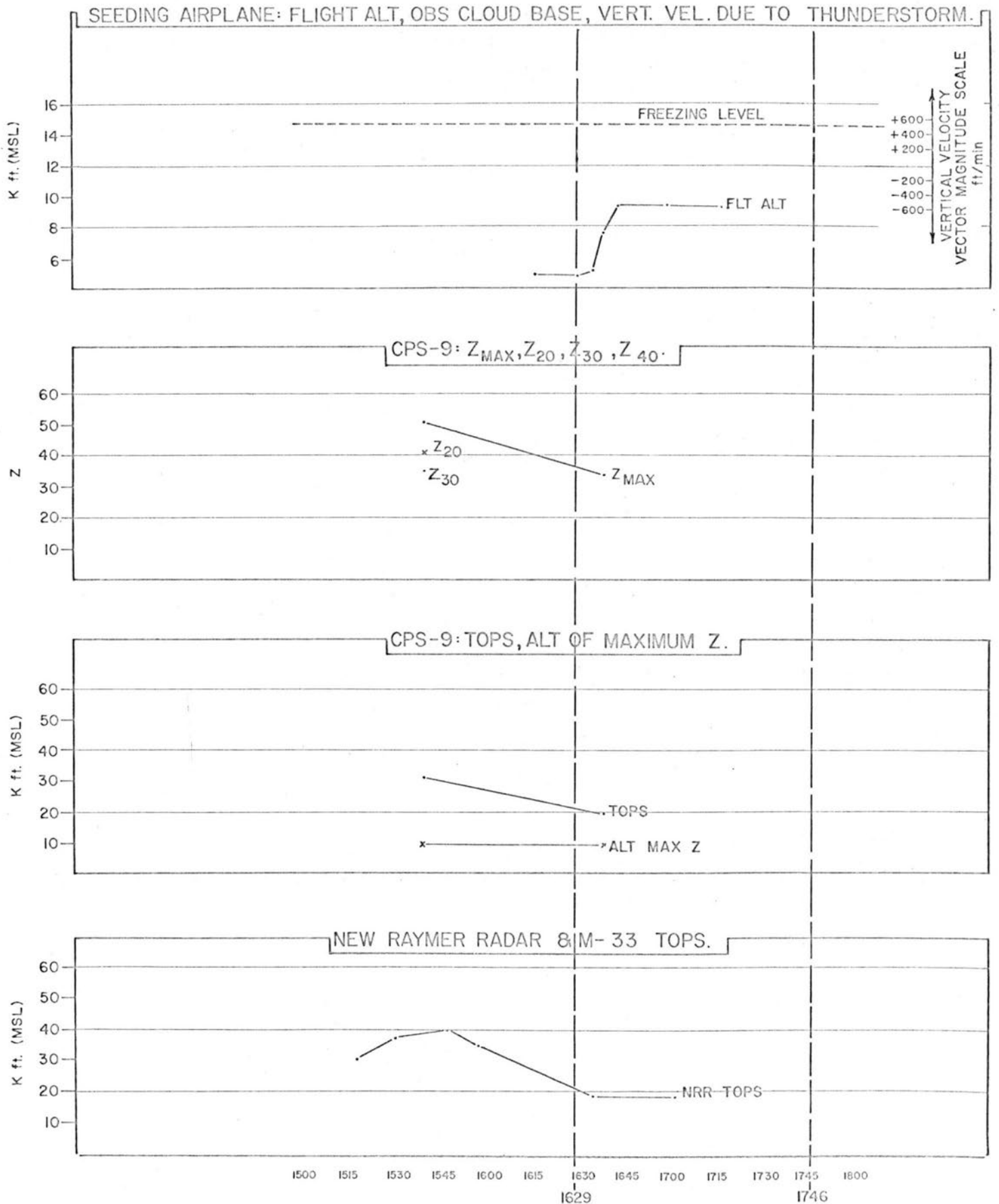
3.



4.

12 JULY-1963

FIGURE J



TEST CASE OF 22 JULY 1963

Test Case Began 1633 MST, Ended 1755 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 8.3 gms/min. Equipment Used: Fuquay Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/4	1	1/4	1	1/4	1
Maximum energy no., ft-lb/ft ²	31	1	97	1	1	1
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	30,000	1	31,000	1	NA	0
Radar tops K-ft MSL, NRR	42,000	2	48,500	2	NA	0
CPS-9 radar reflectivity, Z ₃₀	15	1	15	1	NA	0
Area covered by radar echo, mi ²	571*	2	381*	3	457	2
Rainfall-volume, acre-feet	32.1		18.2		23.4	
Maximum updraft, ft/min.	NA	0	NA	0	1,000	1

*Attenuation .

SIGNIFICANT FEATURES

The surface weather map shows a low pressure area centered over northeastern Colorado for all of this date. Upper level flow was from the southwest.

After approximately one hour of seeding on this test case, severe turbulence was encountered that produced damage on the underside of the airplane wing from the silver iodide generator hitting the bottom of the wing. The test case was terminated after this incident.

The test cell was a strong thunderstorm with

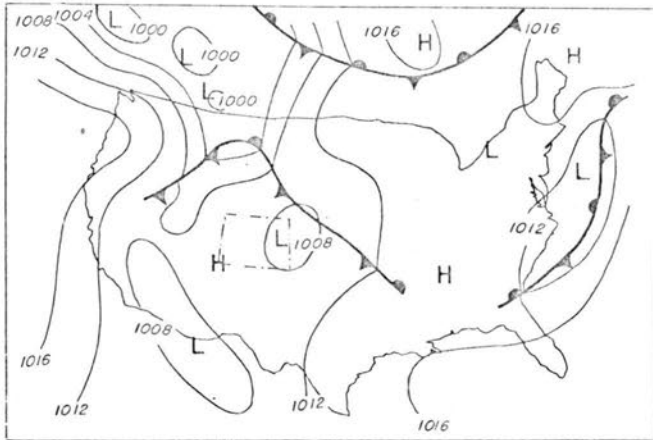
severe turbulence in the updraft areas in advance of the storm.

This test case was associated with a squall line passage over the area. The squall line developed to the point of being very severe and producing quite a lot of rain and some hail over a large portion of the area.

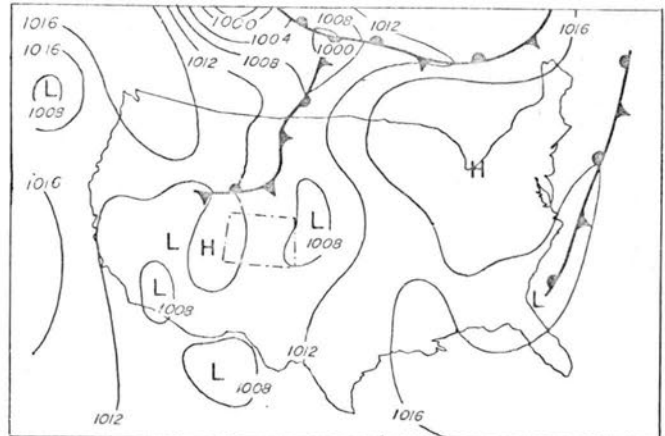
Very little radar data was taken since the data collection ceased shortly after the beginning of the test case. Due to the squall line situation and the general high frequency of clouds in the area, it was very difficult to take very many good pictures of the test case.

22 July 1953
 U. S. Weather Bureau Synoptic Data

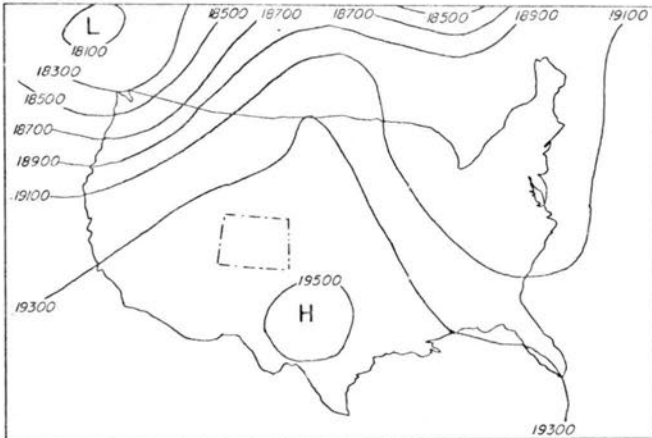
Figures A - F



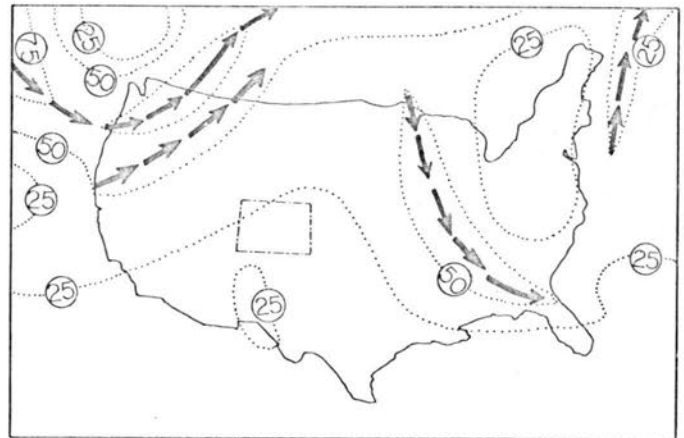
A. Surface Weather Map, 1100 MST (day of test case).



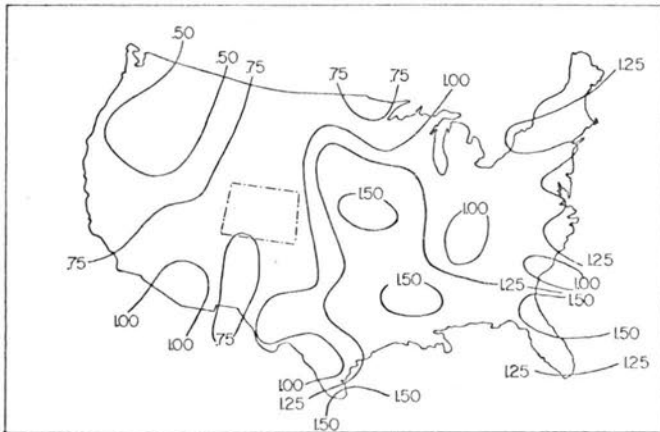
B. Surface Weather Map, 1100 MST (day following test case).



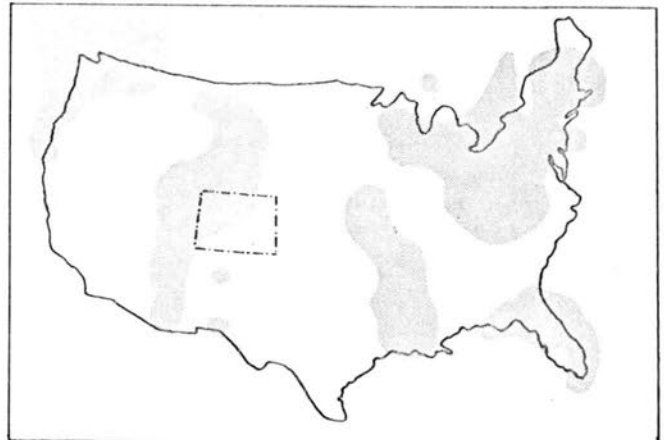
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



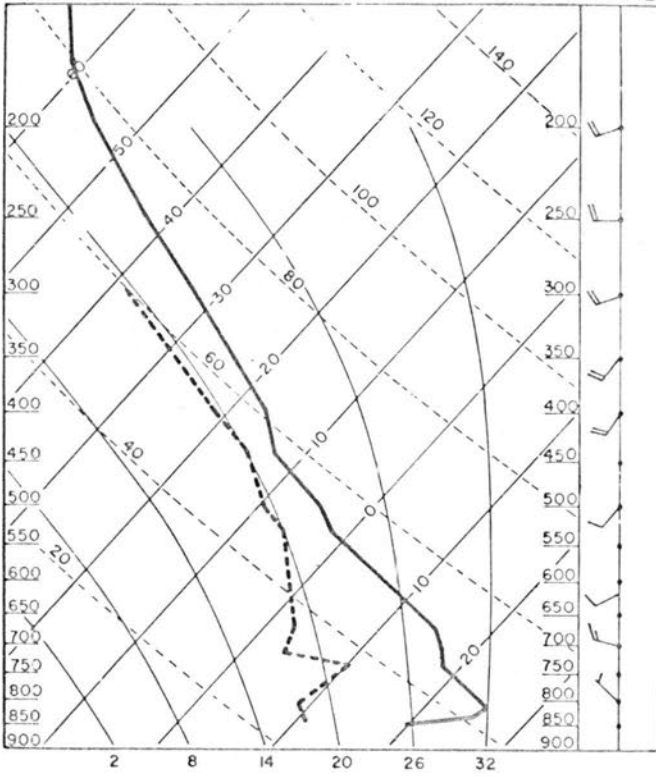
E. Precipitable Water, Inches, 1700 MST.



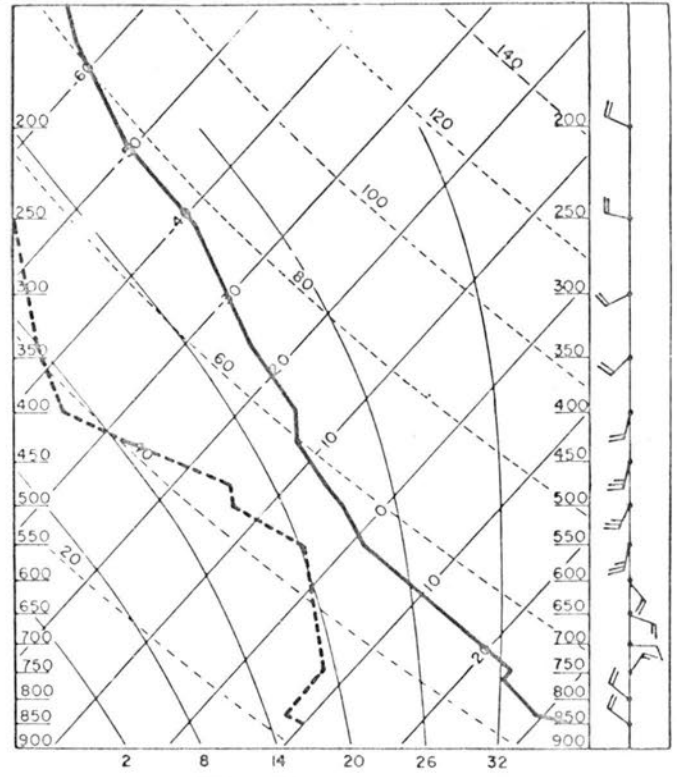
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

22 July 1963
Upper Air Soundings
Skew-T Diagrams

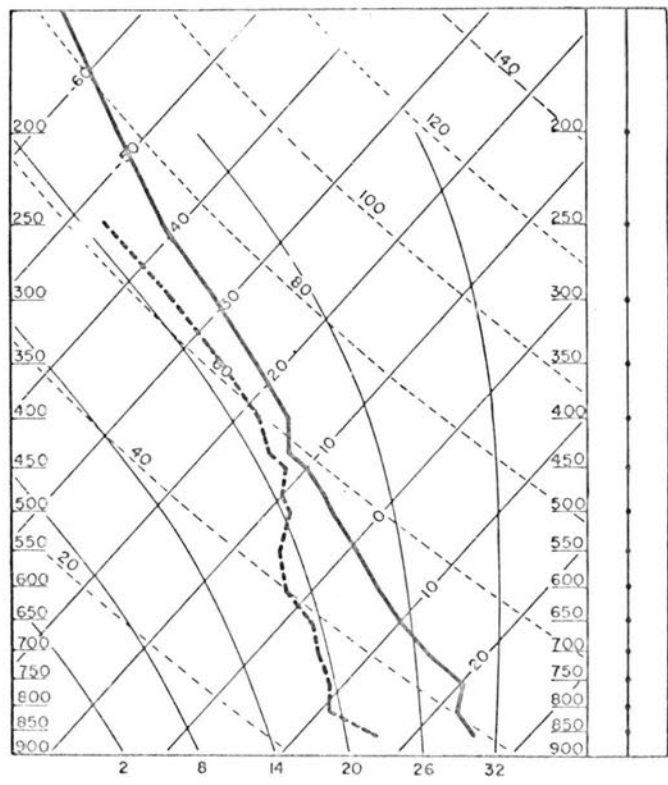
Figure G



1. Denver, 0500 MST.



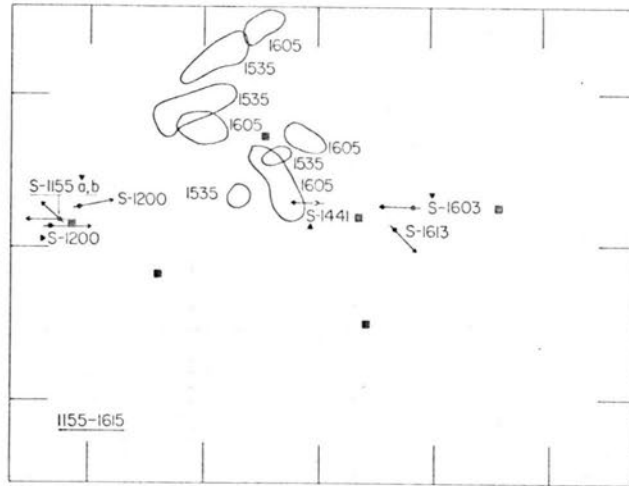
2. Denver, 1700 MST.



3. Fort Collins, 1645 MST.

22 July 1963
Photo Index

Figure H



22 July 1963
Selected Photos



S-1155a Clouds over mountains looking west from Fort Collins.



S-1200 Clouds northeast of Fort Collins.



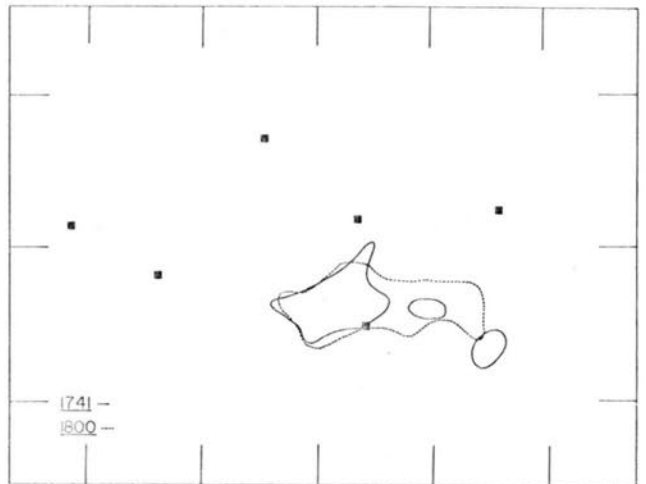
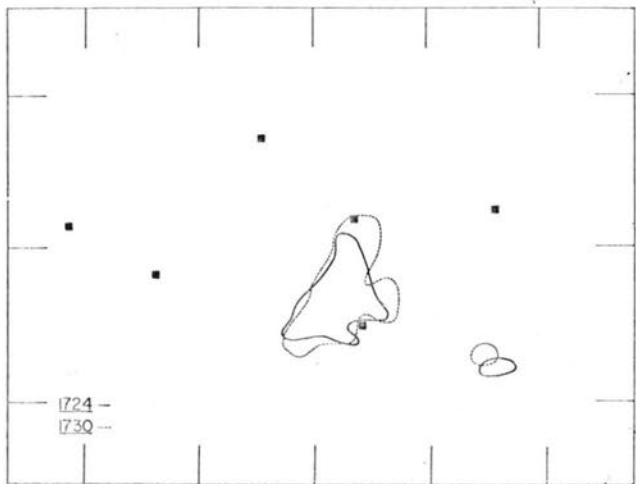
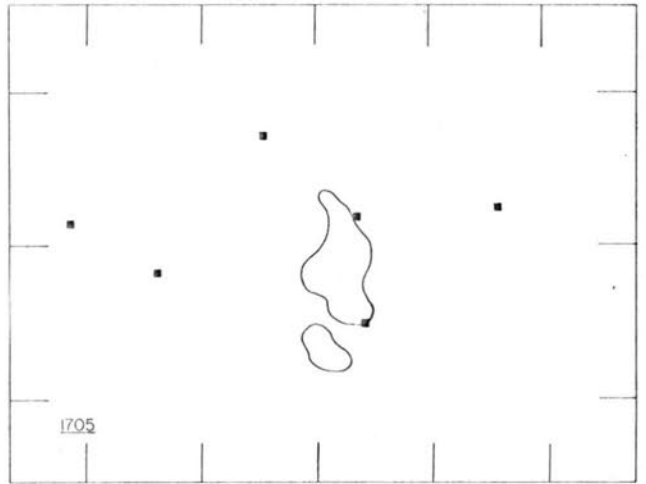
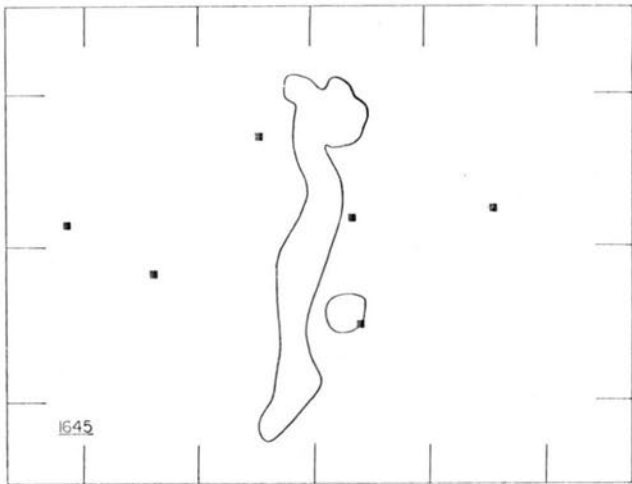
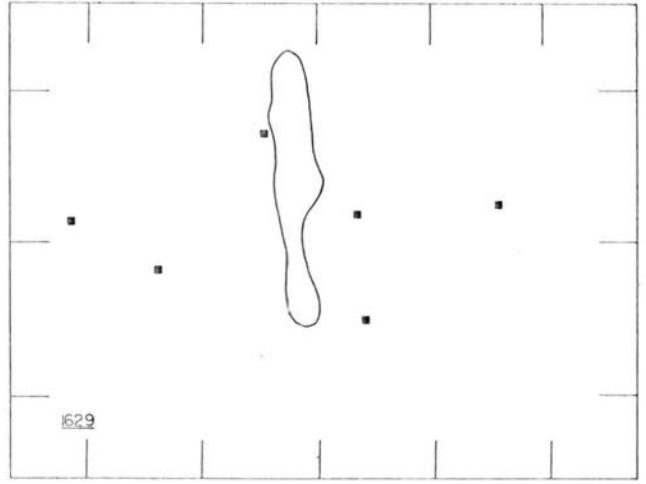
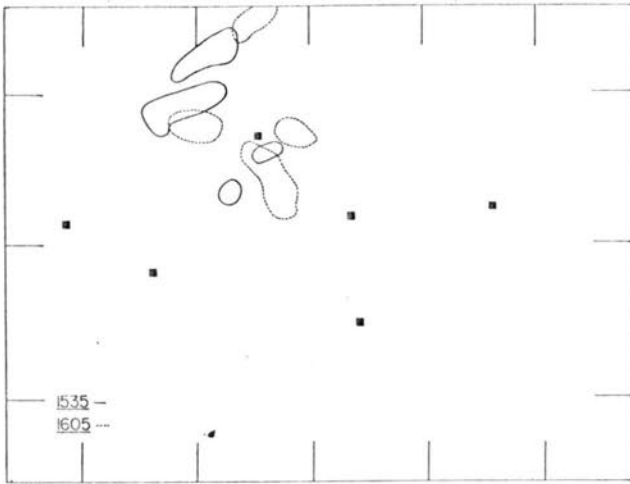
S-1441 Looking west of developing squall line which is to become the test case.



S-1603 Looking west at developing squall line which is to become test case.

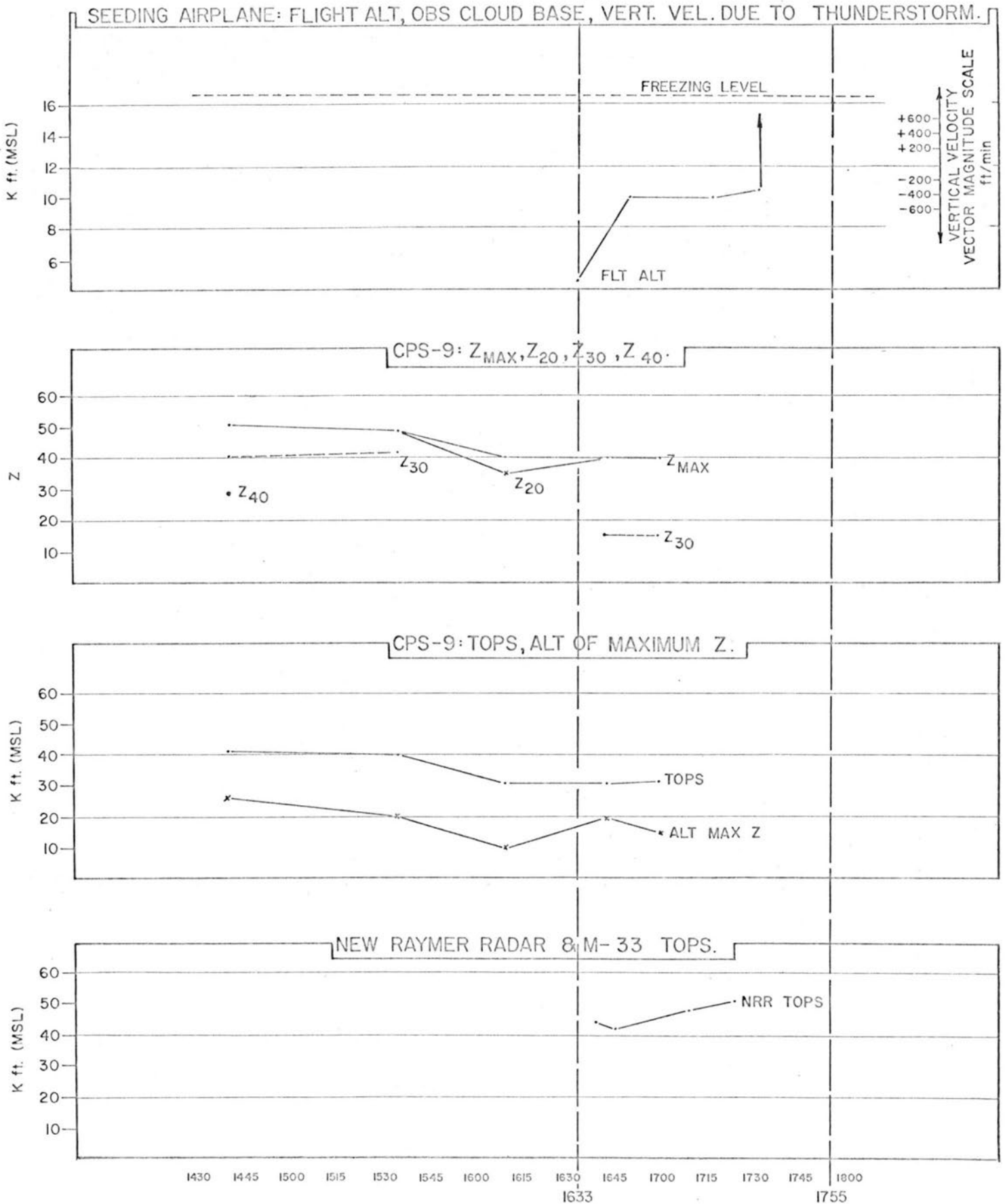
22 July 1963
Radar Echo Positions

Figure I



22 JULY-1963

FIGURE J



TEST CASE OF 25 JULY 1963

Test Case Began 1530 MST, Ended 1630 MST

Seeded: NO Material Used: None

Rate of Seeding: None

Equipment Used: None

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	31,000	1	NA	0
Radar tops K-ft MSL, NRR	NA	0	51,333	3	45,000	2
CPS-9 radar reflectivity, Z ₃₀	NA	0	39	2	NA	0
Area covered by radar echo, mi ²	211	1	160	1	119	1
Rainfall-volume, acre-feet	NA	0	NA	0	NA	0
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

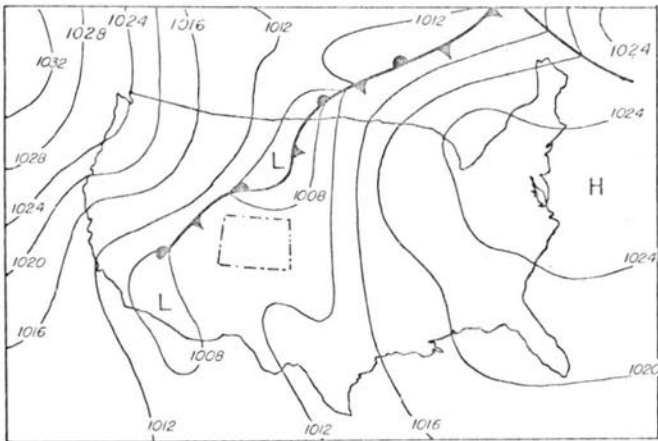
SIGNIFICANT FEATURES

Northeastern Colorado remained in the warm air ahead of an advancing Pacific cold front during this date. Upper level flow was from the southwest and a general cloud cover developed during the day that included moderate precipitation reaching the ground from thunderstorms.

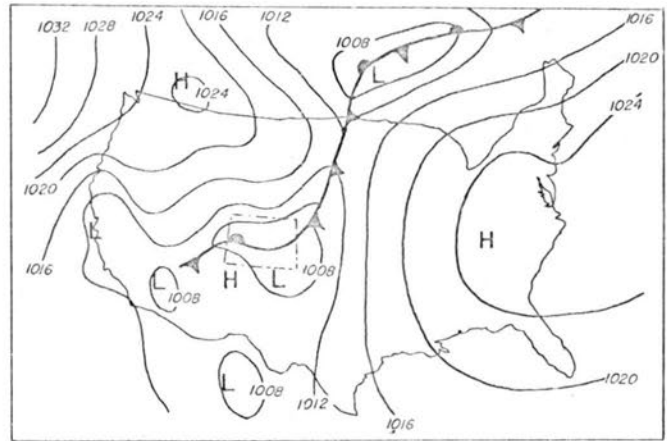
The seeding aircraft was equipped with the Navy pyrotechnic seeding devices (Alectos), but no seeding was done because a malfunction occurred that prevented utilization of these devices.

25 July 1963
 U. S. Weather Bureau Synoptic Data

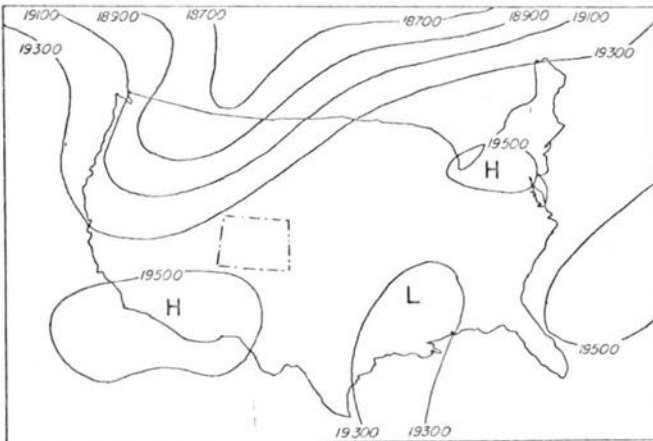
Figures A - F



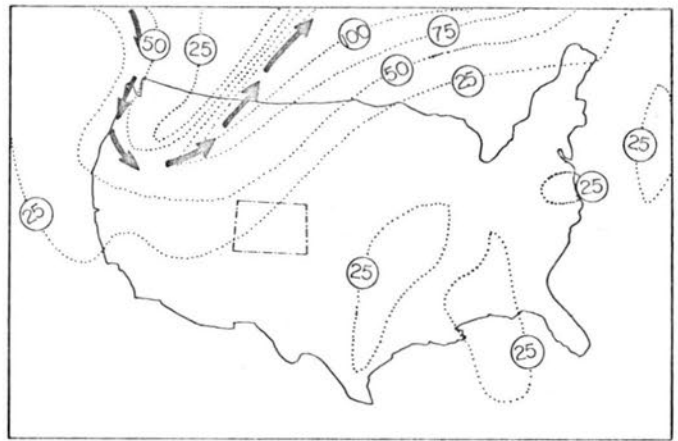
A. Surface Weather Map, 1100 MST (day of test case).



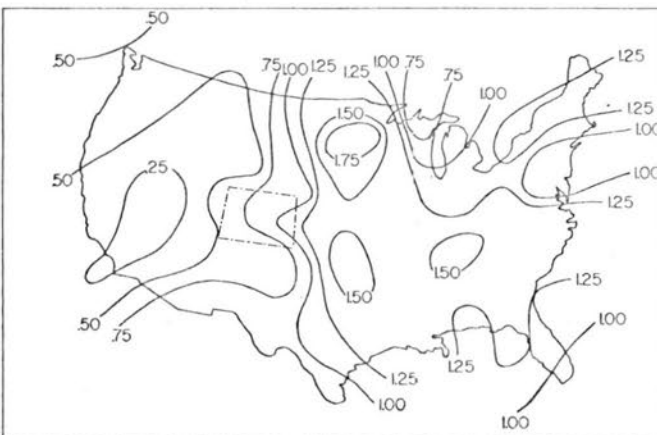
B. Surface Weather Map, 1100 MST (day following test case).



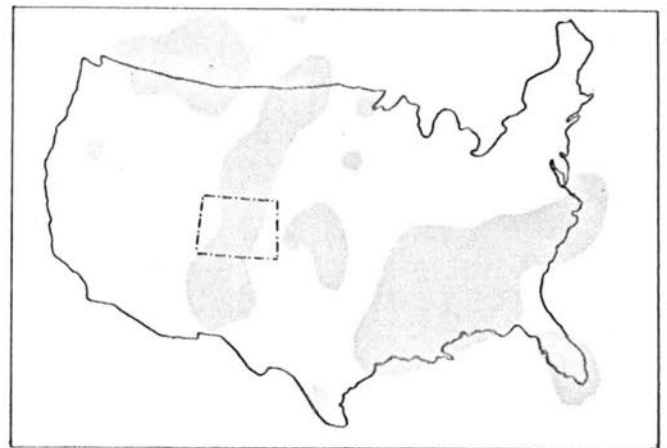
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



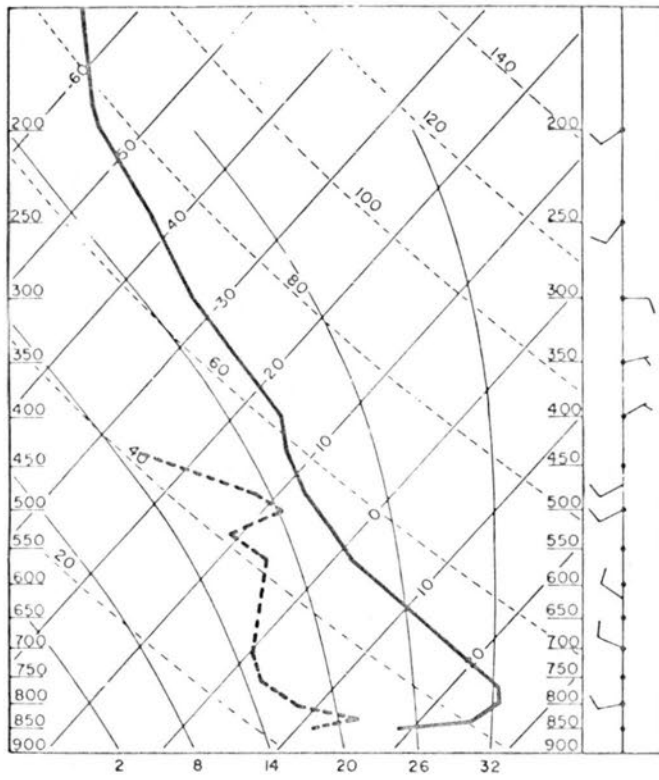
E. Precipitable Water, Inches, 1700 MST.



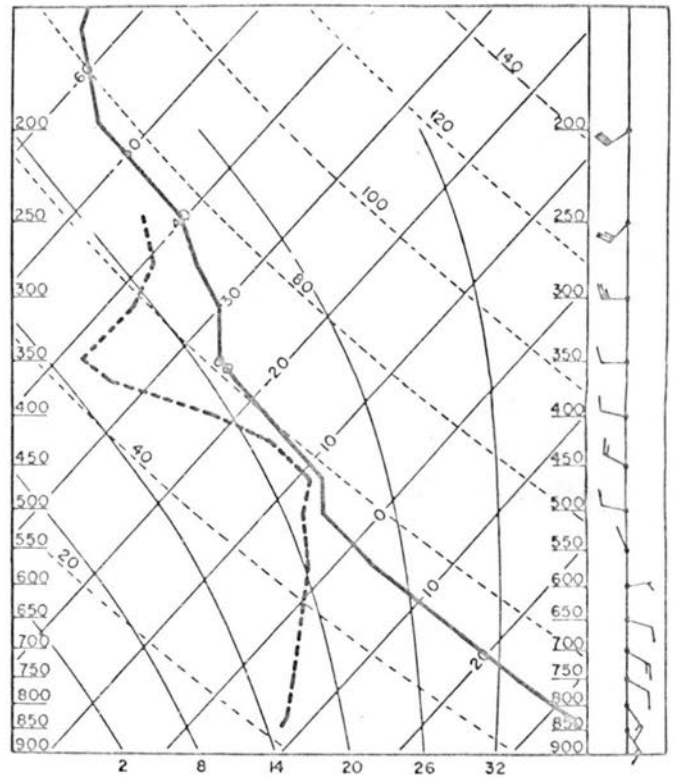
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

25 July 1963
Upper Air Soundings
Skew-T Diagrams

Figure G



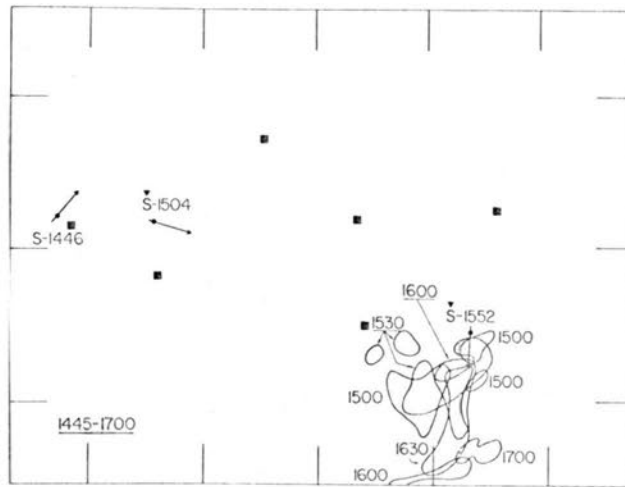
1. Denver, 0500 MST.



2. Denver, 1700 MST.

25 July 1963
Photo Index

Figure H



1.

25 July 1963
Selected Photos



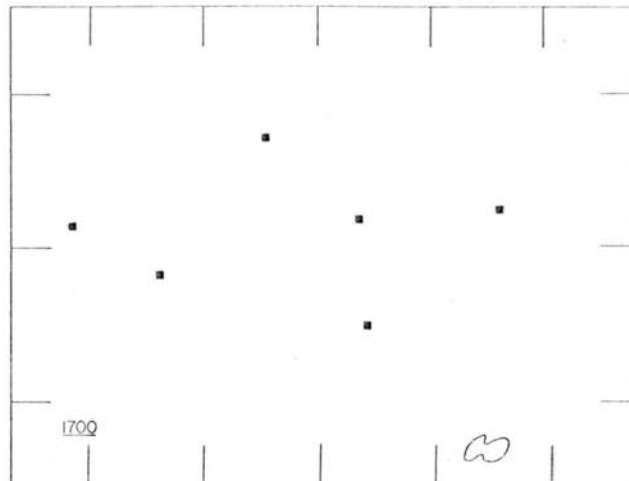
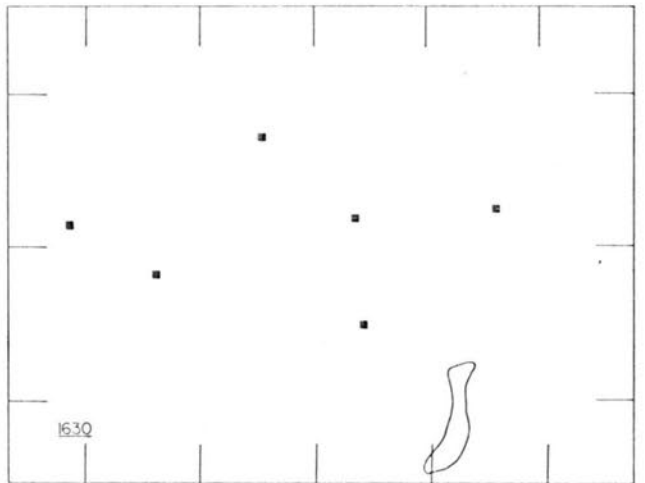
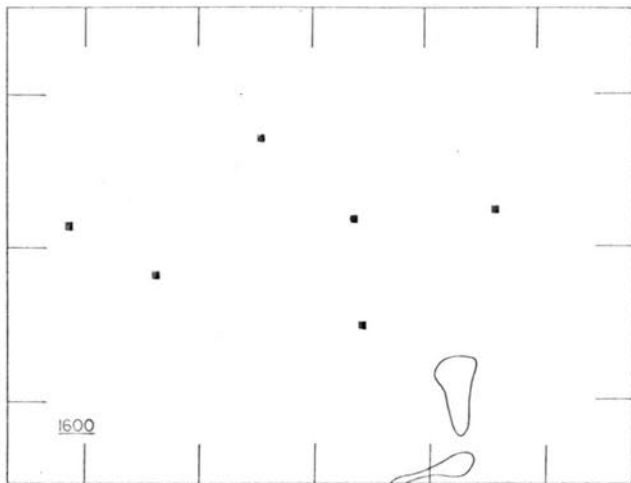
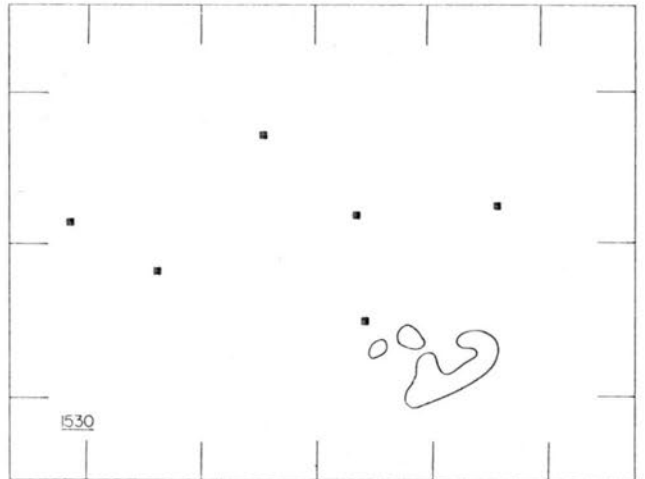
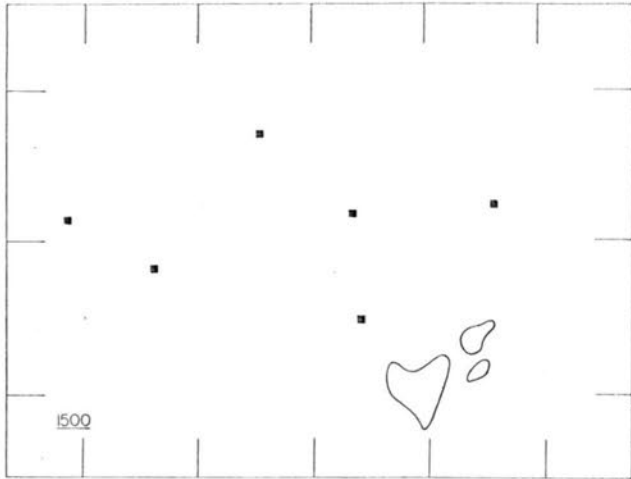
S-1504 Looking southeast from north of
Greeley at general cloud pattern.



S-1552 Looking south at the east edge of the
test case.

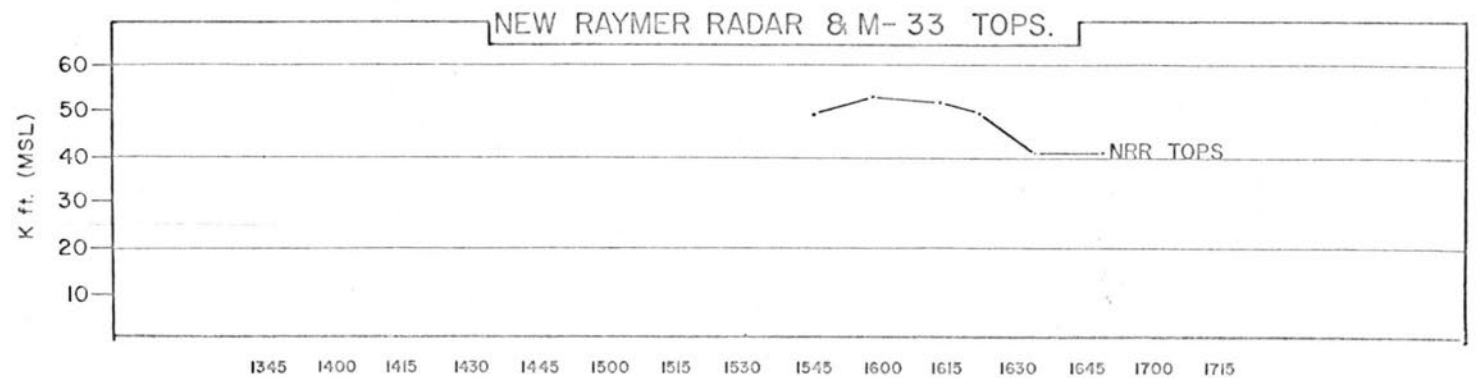
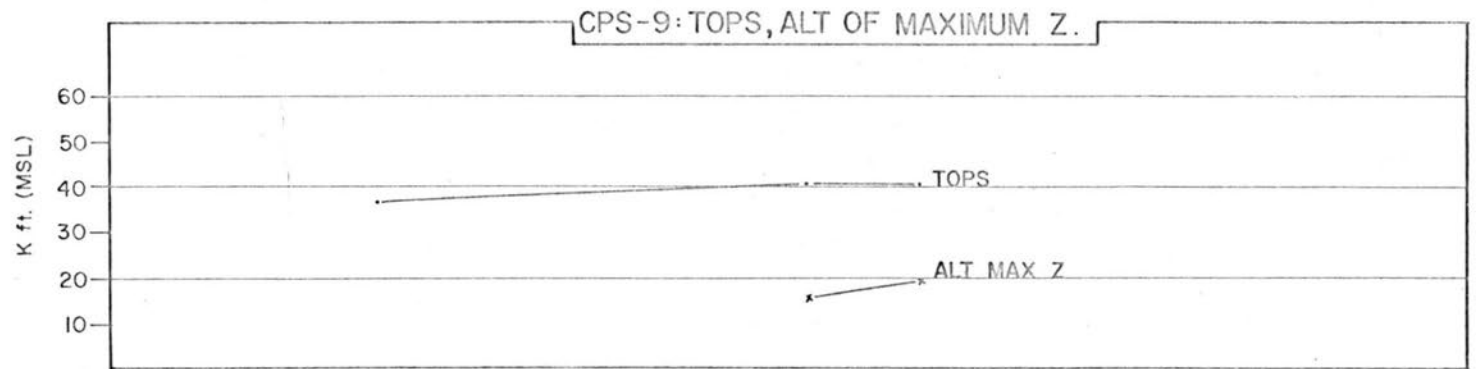
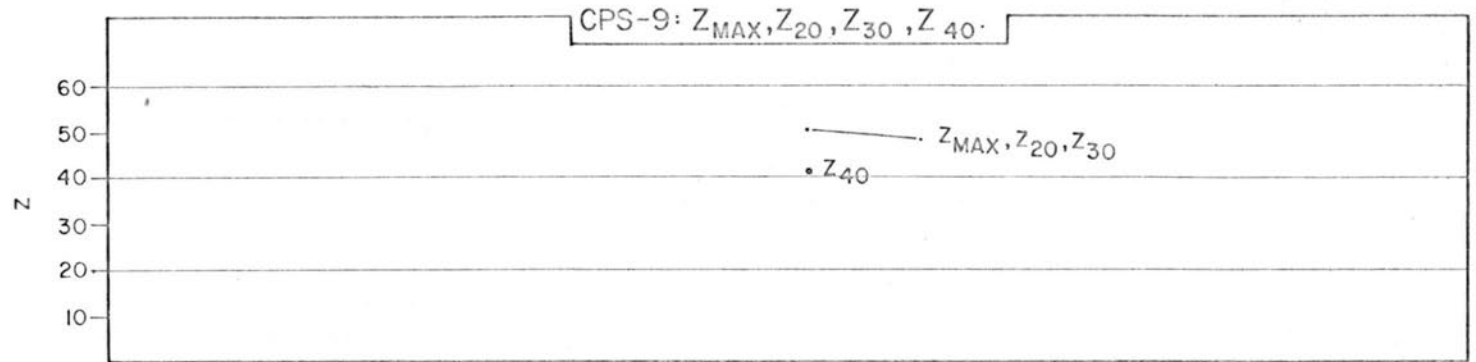
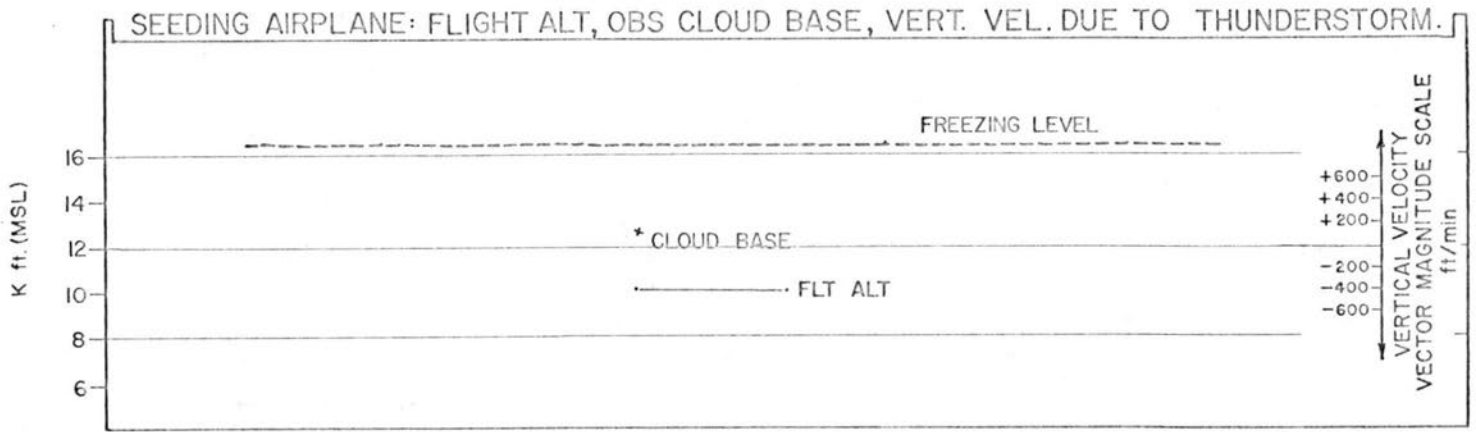
25 July 1963
Radar Echo Positions

Figure I



25 JULY-1963

FIGURE J



1345 1400 1415 1430 1445 1500 1515 1530 1545 1600 1615 1630 1645 1700 1715

TEST CASE #1 OF 26 JULY 1963

Test Case Began 1529 MST, Ended 1534 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 1770 gms/min. Equipment Used: 5-USN Alecto

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	1	1	1/4	1
Maximum energy no., ft-lb/ft ²	NA	0	123	1	25	1
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	NA	0	54,000	1
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	NA	0	NA	0	209*	1
Rainfall-volume, acre-ft.	7.9		10.8		13.0	
Maximum updraft, ft/min.	1250	2	NA	0	NA	0

*Attenuation

TEST CASE #2 OF 26 JULY 1963

Test Case Began 1654 MST, Ended 1703 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 1770 gms/min. Equipment Used: 4-USN Alecto

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	1/4	1	1/8	1	NA	0
Maximum energy no., ft-lb/ft ²	25	1	31	1	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	NA	0	NA	0	NA	0
Rainfall-volume, acre-ft.	14.7		15.1		13.6	
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

SIGNIFICANT FEATURES

Northeastern Colorado was in the cooler air behind a cold front extending from south-central Nebraska to south-central Colorado during this date. Upper level flow was from the southwest with a jet stream from western Wyoming to the western Dakotas.

Two cloud systems were each seeded with U. S. Navy "Alecto" units. Radar documentation was possible only on the first test case beginning at 1529 and ending at 1534. Seeding was accomplished on a second cell beginning at 1654 and ending at 1703, but radar data was not available because of a power failure at the beginning of seeding of the second case.

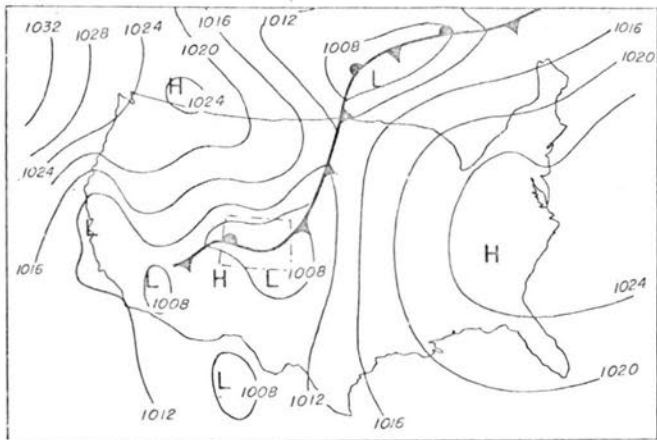
A review of the radar data on the first case indicates a rapid rate of advance of the radar echo on the PPI scope, at a rate of approximately 100 knots in the ten minute interval following the time of seeding with the "Alecto" units.

The squall line from which the test cell was taken gave intense rain at Sterling. Record-breaking rainfalls occurred at Sterling as the system passed about 40 miles east of the New Raymer radar.

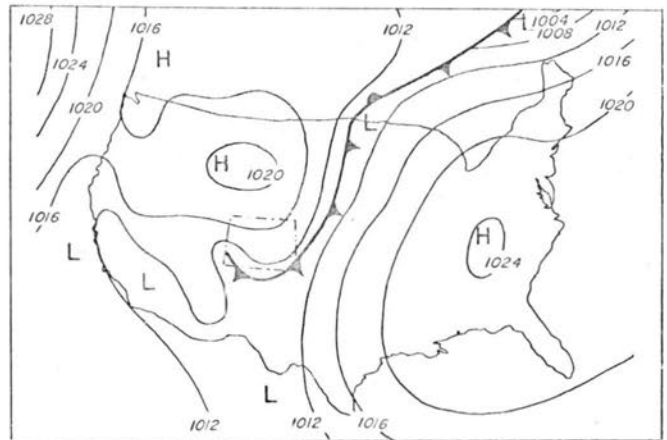
This was a case of massive seeding for a short time. The rate of growth was felt to be significant during this test case.

26 July 1963
 U. S. Weather Bureau Synoptic Data

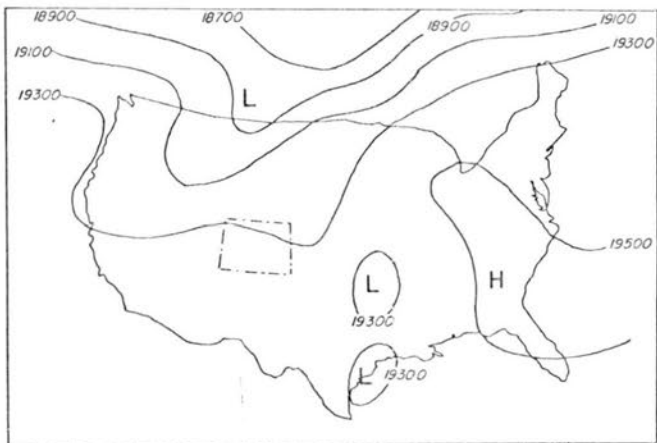
Figures A - F



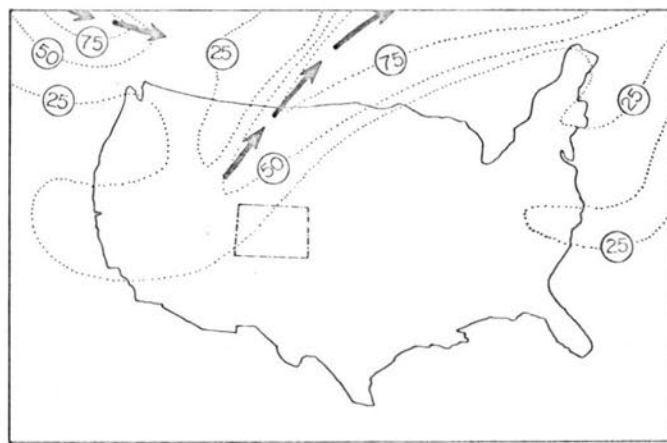
A. Surface Weather Map, 1100 MST (day of test case).



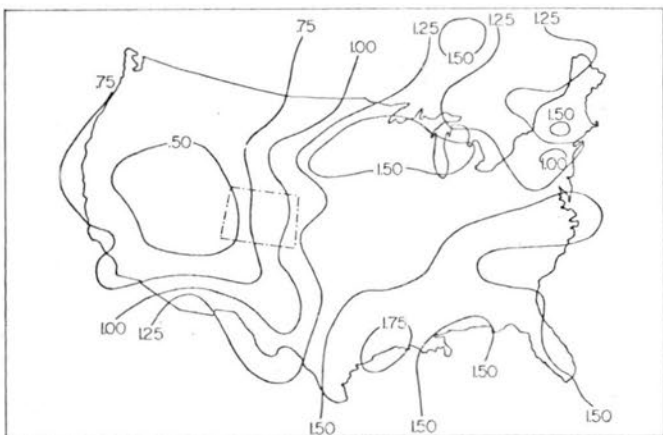
B. Surface Weather Map, 1100 MST (day following test case).



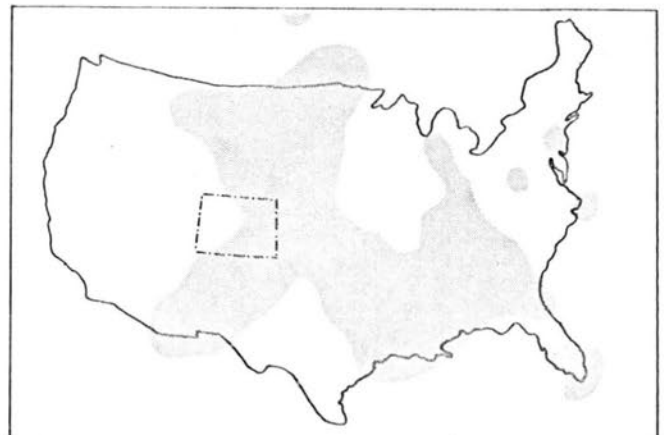
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



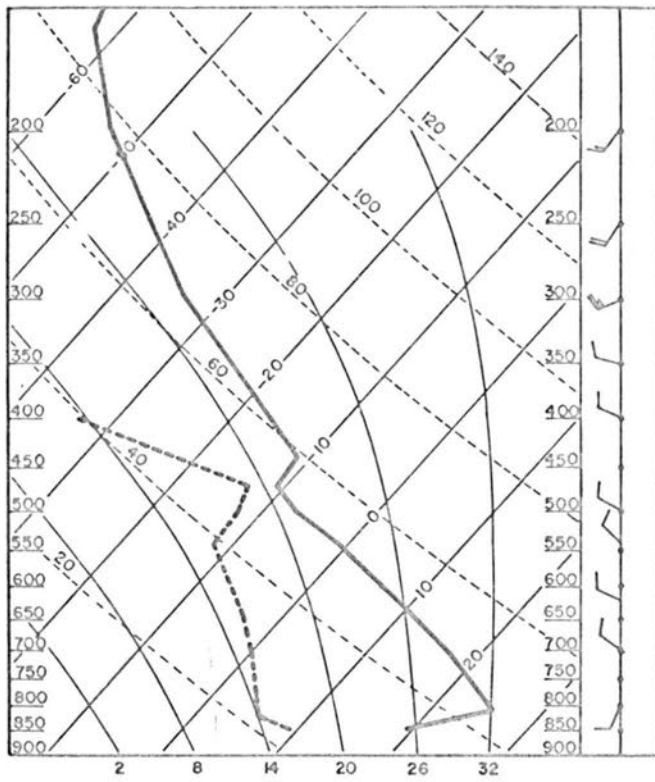
E. Precipitable Water, Inches, 1700 MST.



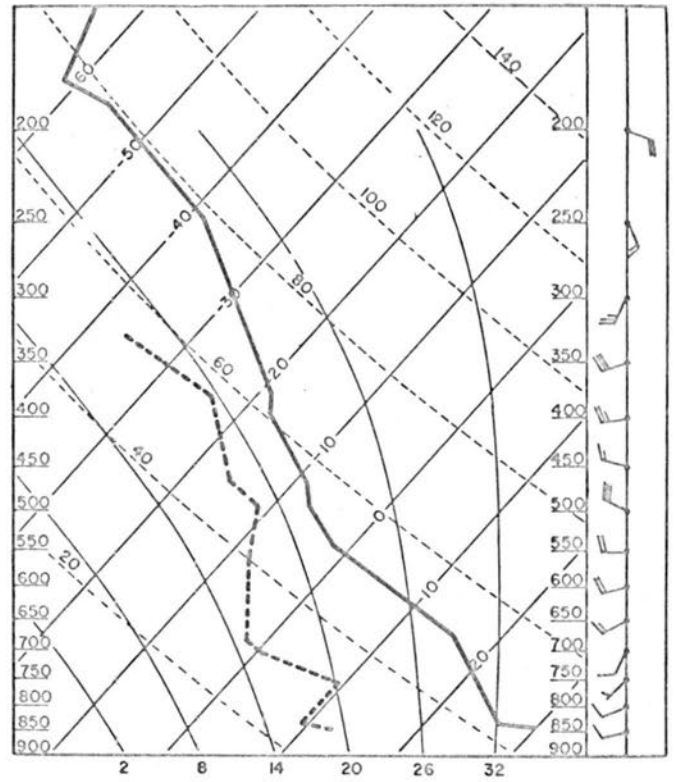
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

26 July 1963
Upper Air Soundings
Skew-T Diagrams

Figure G



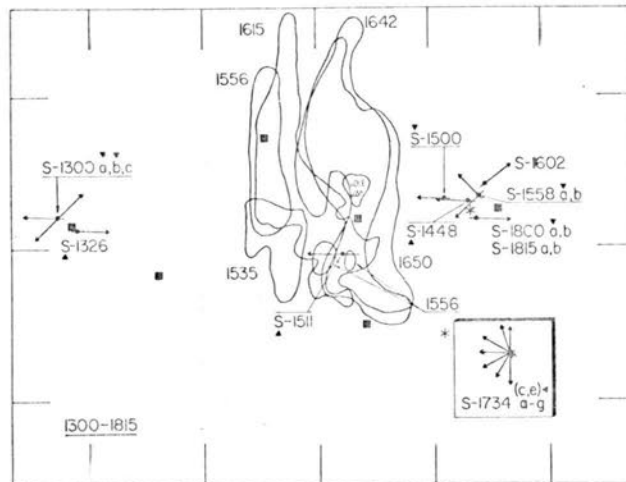
1. Denver, 0500 MST.



2. Denver, 1700 MST.

26 July 1963
Photo Index

Figure H



1.

26 July 1963
Selected Photos



S-1300a Looking southwest from Fort Collins at general cloud cover coming over the mountains.



S-1300b Looking west from Fort Collins at general cloud cover coming over the mountains.



S-1326 Looking east from over Fort Collins. Note high cirrus and general scarcity of clouds.



S-1448 Cumulus developing west of Sterling. This is to become the first test case.



S-1500 Cumulus developing west of Sterling. This is to become the first test case.



S-1511 Looking west at the south edge of what is to become the first test case, eighteen minutes before seeding begins.

26 July 1963
Selected Photos



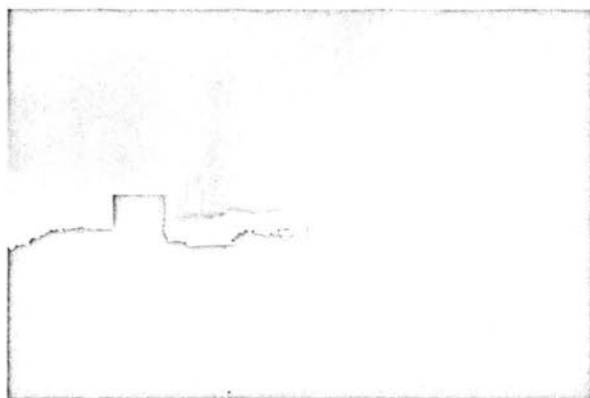
S-1558a Looking at the low scud clouds preceding test case #1, twenty-four minutes after seeding ended.



S-1734a Test case approaching Sterling from the west. Note low cumulus clouds.



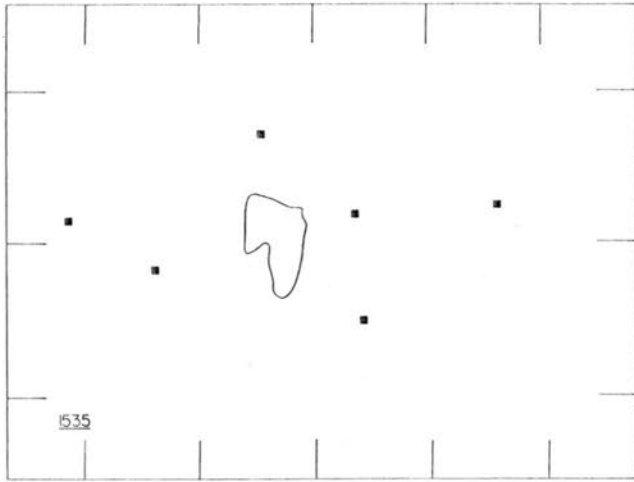
S-1734e Looking west-northwest from Sterling showing approaching storm. Note roll cloud along leading edge.



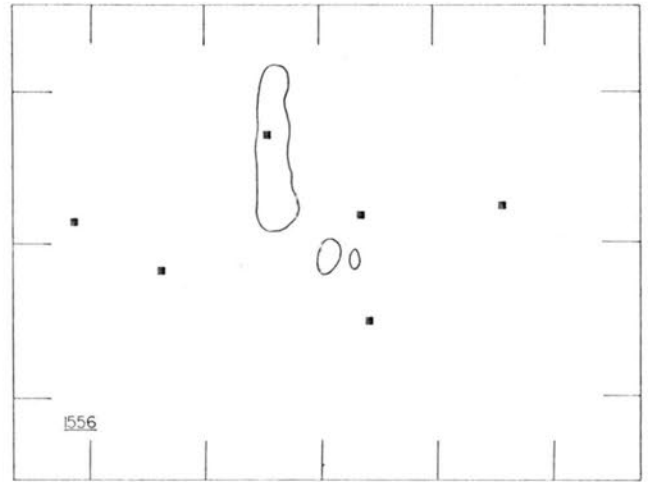
S-1800a Looking east from Sterling at passing test case. One hour after termination of test cases for the day.

26 July 1963
Radar Echo Positions

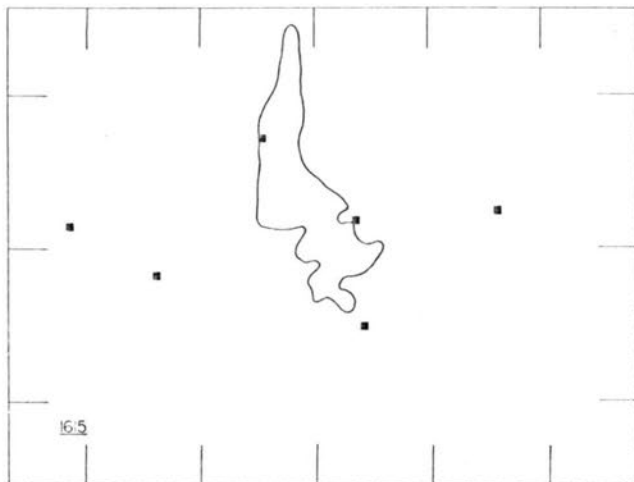
Figure I



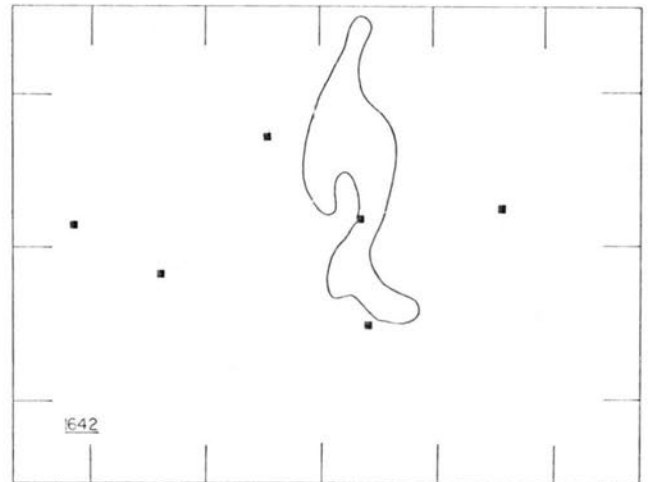
1.



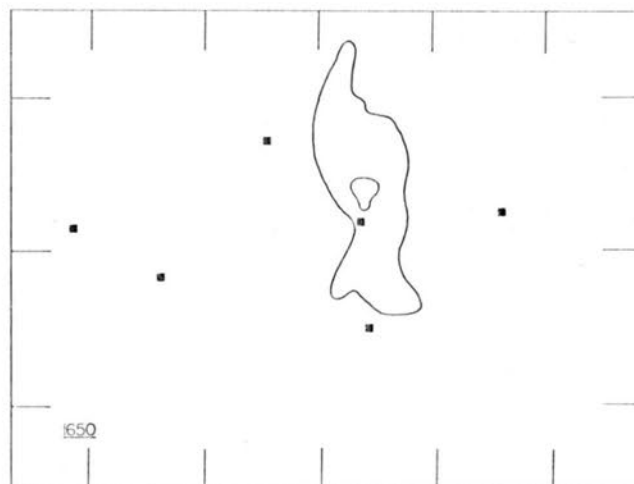
2.



3.



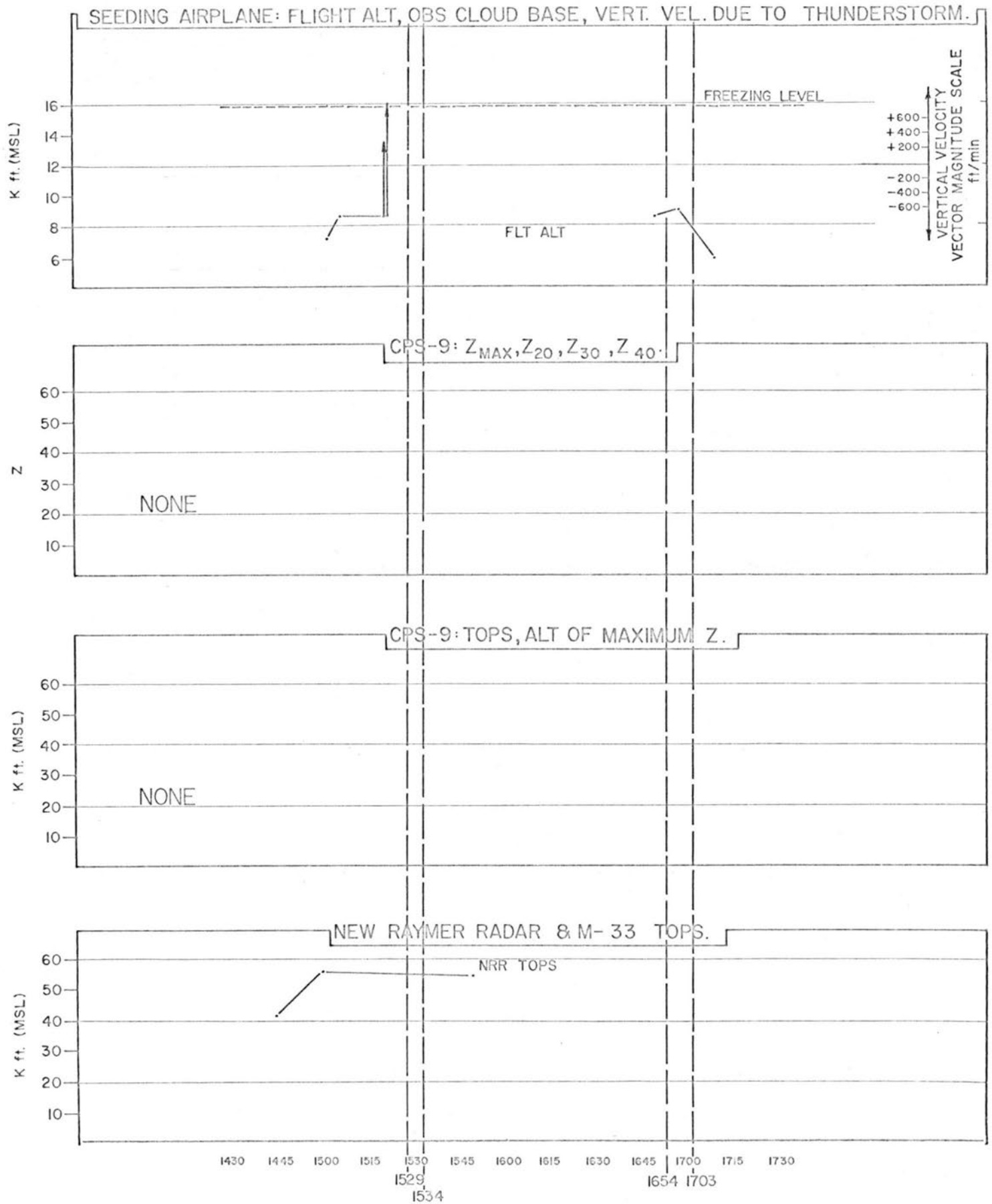
4.



5.

26 JULY-1963

FIGURE J



TEST CASE OF 26 JULY 1962

Test Case Began 1608 MST, Ended 1650 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 30 gms/min. Equipment Used: C. S. U. Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	3/4	1	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	92	1	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	495	1	NA	0	156	1
Rainfall-volume, acre-ft.	30.1		17.6		18.8	
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

SIGNIFICANT FEATURES

The surface weather map shows a stationary front in northeast Colorado during the time of this test case. Upper level flow was from the west with the strongest circulation being east of the test area.

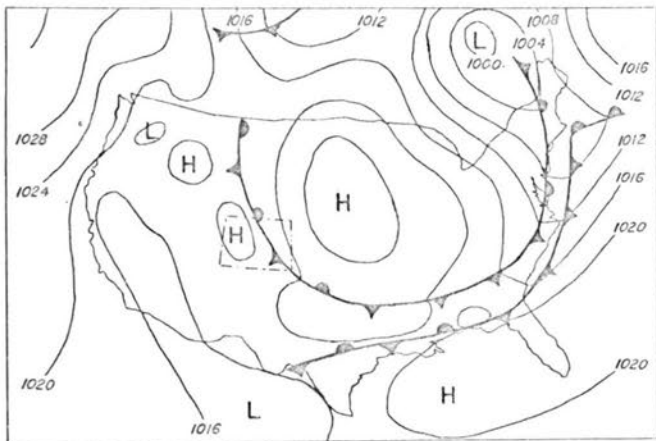
The rainfall pattern from the storms on this date was extremely variable (see Figure M). One of the features of this day's operation was the dropping of approximately five pounds of sodium chloride from the aircraft into the base of one of the cumulus clouds. No significant changes could be observed in that cloud from radar data.

During this test case, it was necessary to seed on the west side of a squall line since it was impossible for the airplane to get through the line to work on the leading edge. Towards the end of the seeding run, the seeding device started to plug up and perhaps did not put out the expected amount of silver iodide crystals.

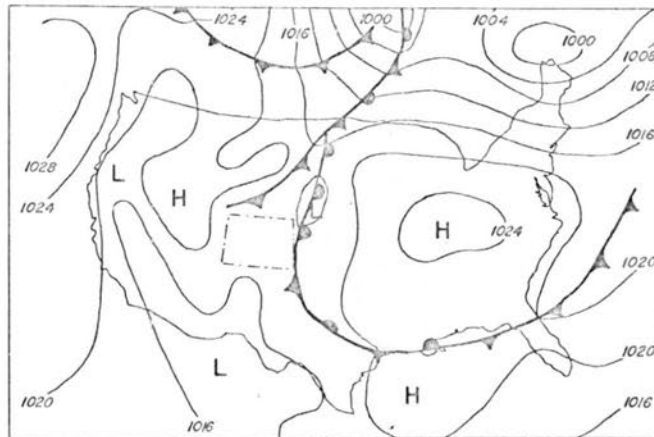
The seeding device used on this test case was designed and built by CSU engineers. This device sprayed out a solution of silver iodide and ammonia.

26 July 1962
 U. S. Weather Bureau Synoptic Data

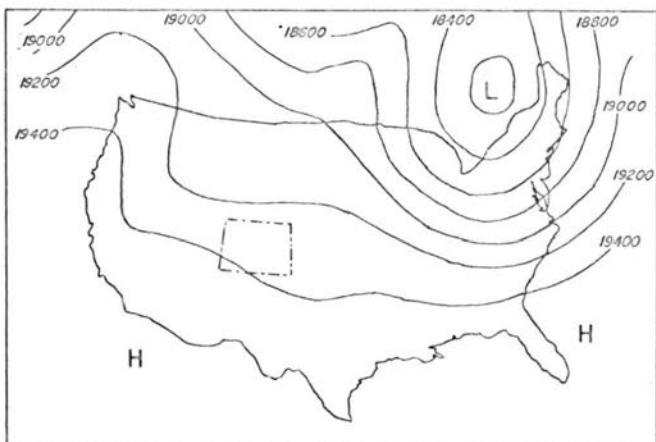
Figures A - F



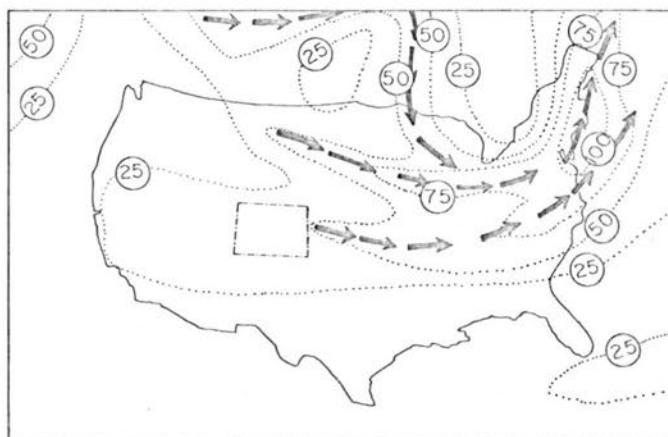
A. Surface Weather Map, 1100 MST (day of test case).



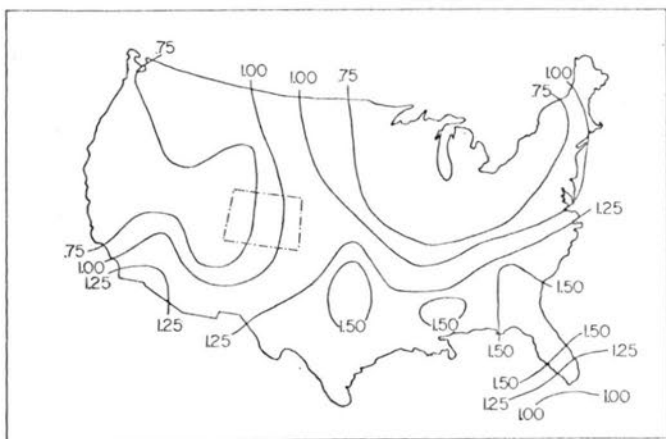
B. Surface Weather Map, 1100 MST (day following test case).



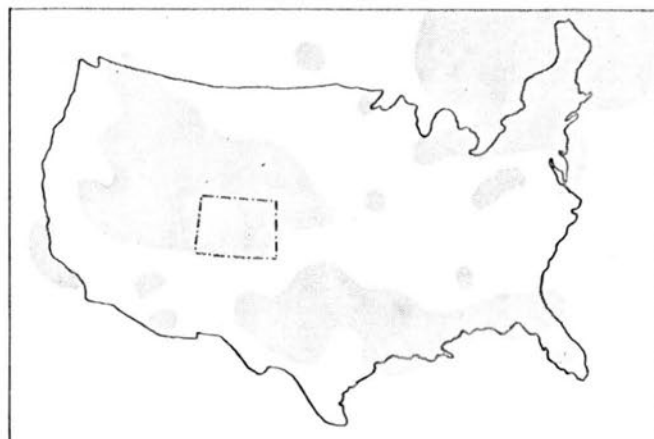
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



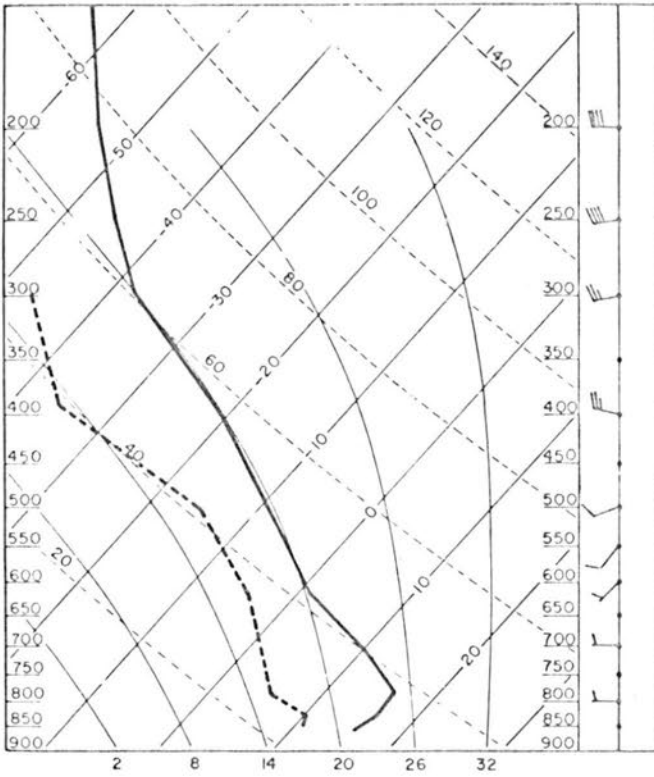
E. Precipitable Water, Inches, 1700 MST.



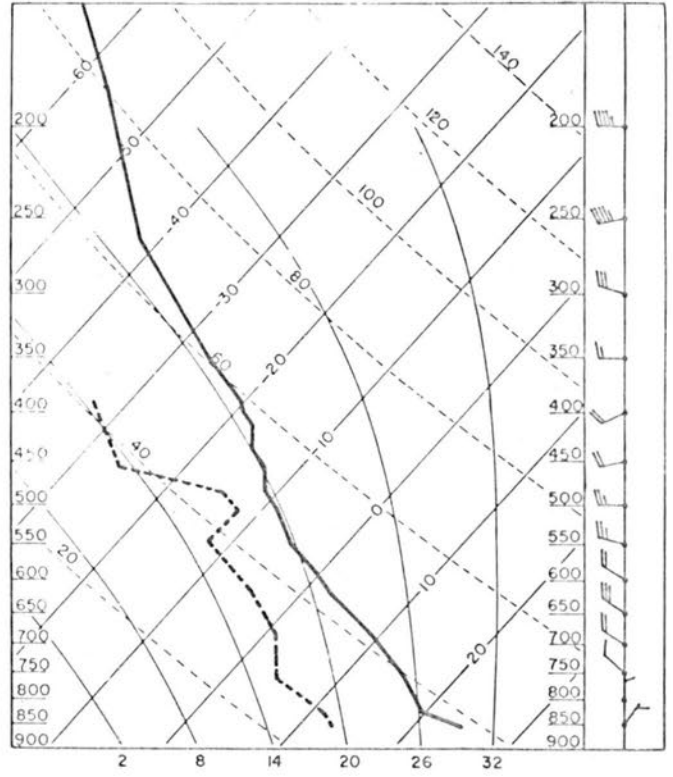
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

26 July 1962
Upper Air Soundings
Skew-T Diagrams

Figure G



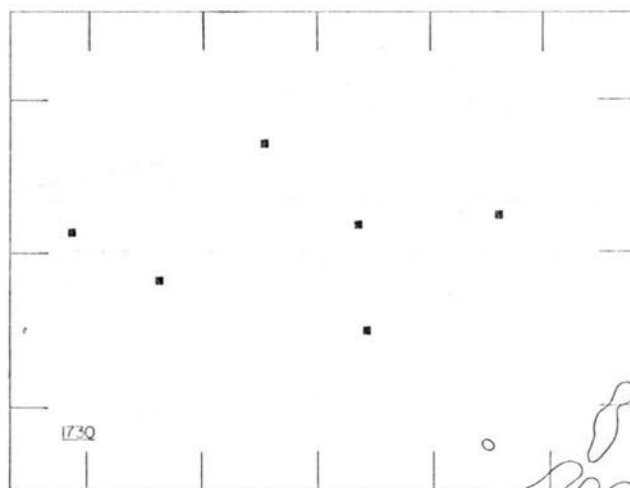
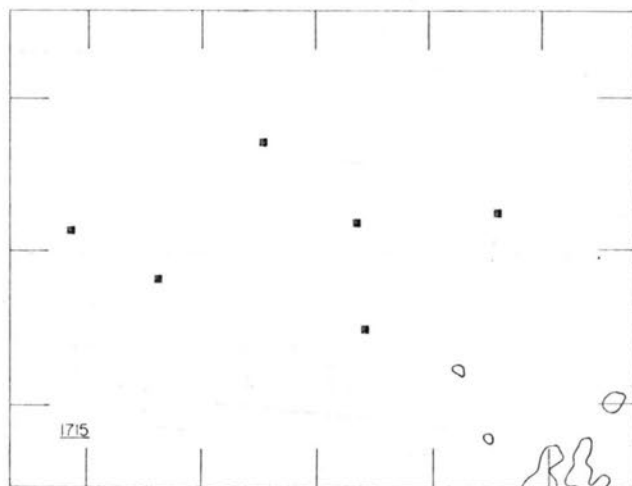
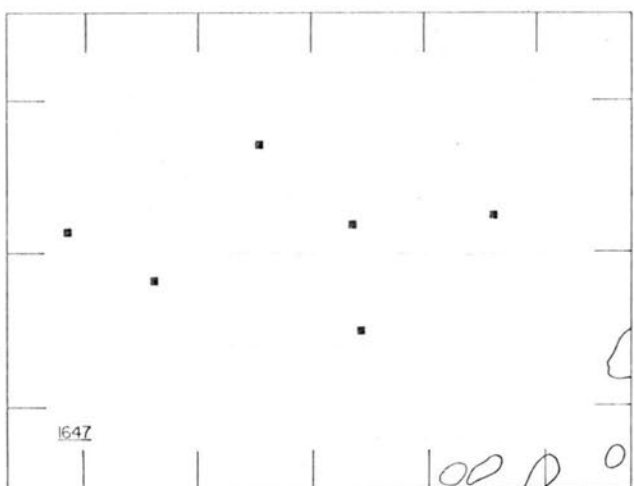
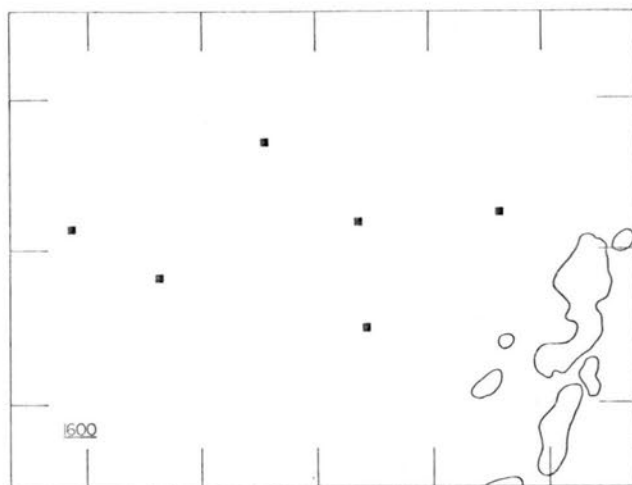
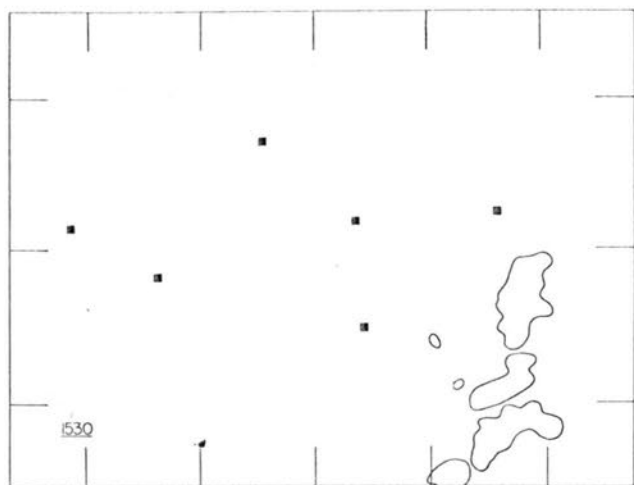
1. Denver, 0500 MST.



2. Denver, 1700 MST.

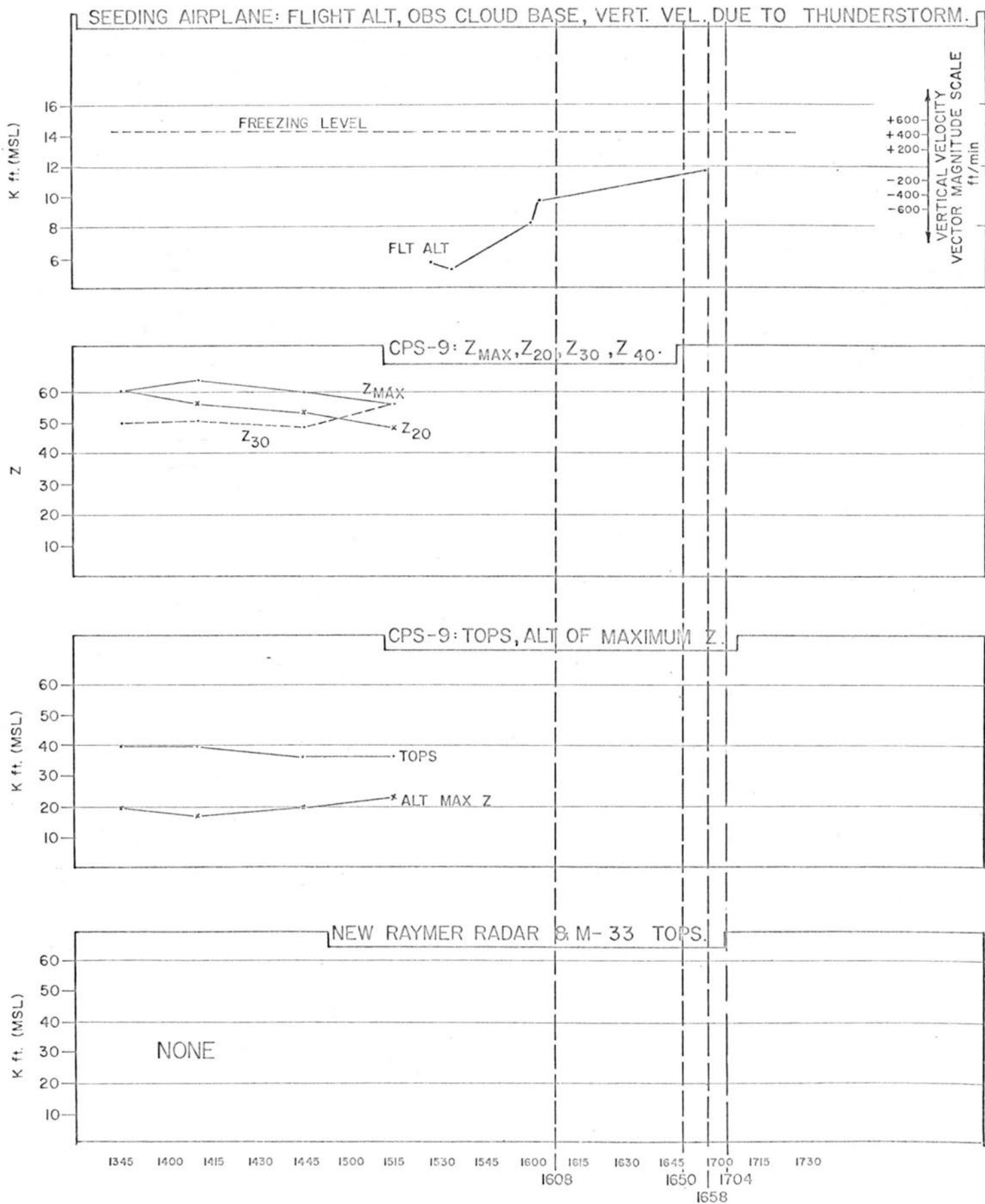
26 July 1962
Radar Echo Positions

Figure I



26 JULY-1962

FIGURE J



TEST CASE OF 30 JULY 1962

Test Case Began 1439 MST, Ended 1517 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 30 gms/min. Equipment Used: C. S. U. Generator

SUMMARY TABLE

Test Case Characteristics	Before		During		After	
	Test Case		Test Case		Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	1/2	1
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	396	1
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	35,000	1
Radar tops K-ft MSL, NRR	41,000	1	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	38	1
Area covered by radar echo, mi ²	NA	0	NA	0	744*	1
Rainfall-volume, acre-feet	12.4		16.1		26.9	
Maximum updraft, ft/min.	NA	0	1,000	1	NA	0

*Attenuation

SIGNIFICANT FEATURES

Northeastern Colorado was under the influence of a light pressure gradient from the southeast, north of a cold front which extended from the Northern Great Lakes into west-central Texas. A weak 500 mb trough existed over south-central Colorado at the time of this test case.

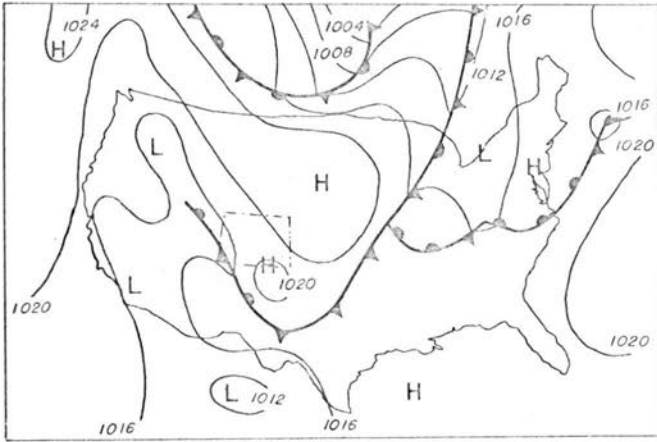
One of the interesting features of this test case was the dropping of approximately five pounds of sodium chloride into the base of developing cumulus clouds north of New Raymer Radar. The clouds

grew rapidly following the time of introduction of this material into the cloud.

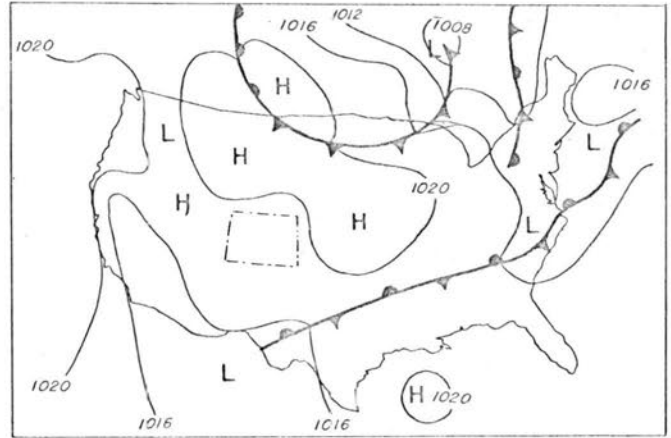
This test case was also seeded with the CSU generator. This device functioned properly for the entire time of the test case. The cell in question appeared to increase in the amount of precipitation.

Little hail occurred in the area but there were areas of quite heavy precipitation over northeastern Colorado.

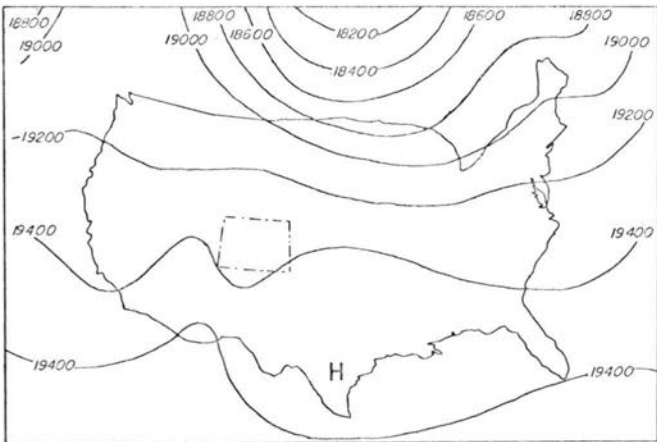
Figures A - F



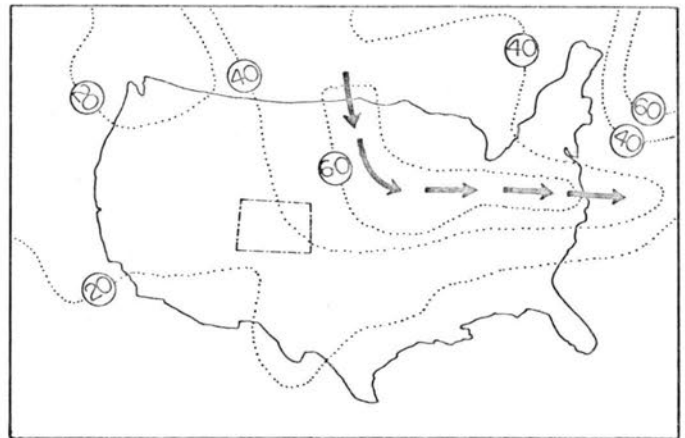
A. Surface Weather Map, 1100 MST (day of test case).



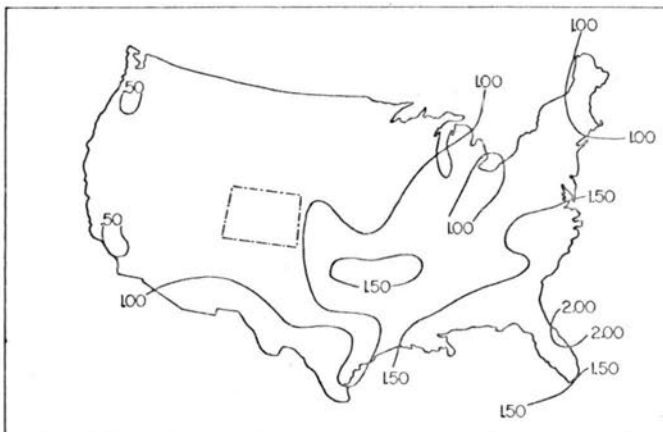
B. Surface Weather Map, 1100 MST (day following test case).



C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



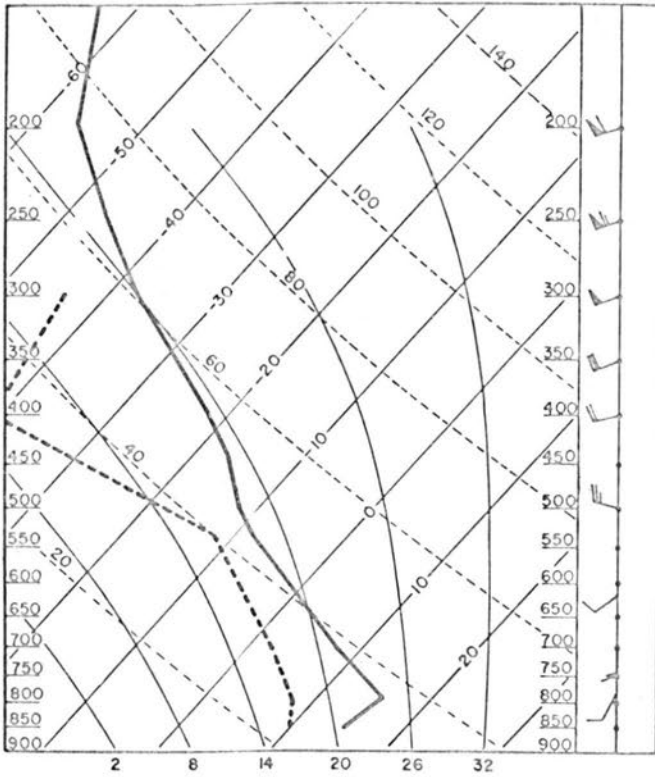
E. Precipitable Water, Inches, 1700 MST.



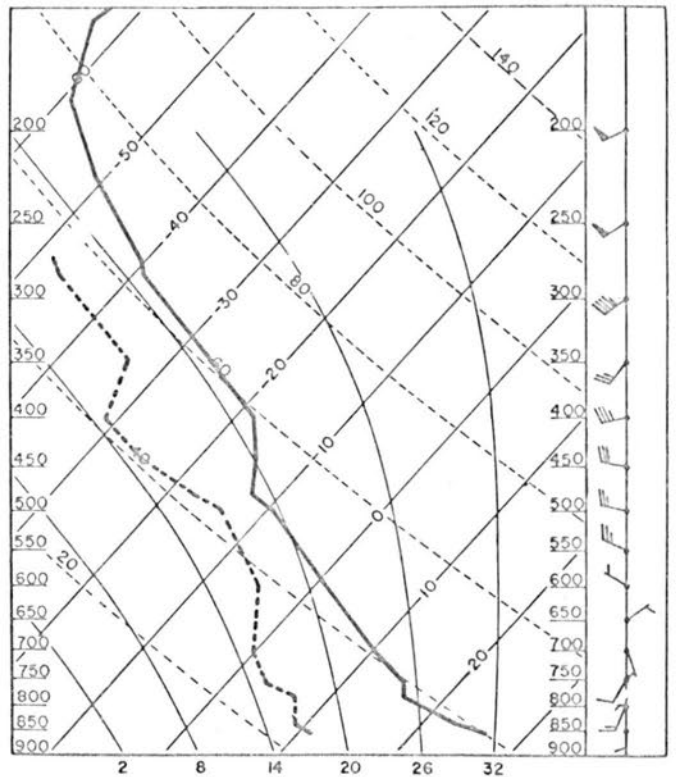
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

30 July 1962
Upper Air Soundings
Skew-T Diagrams

Figure G



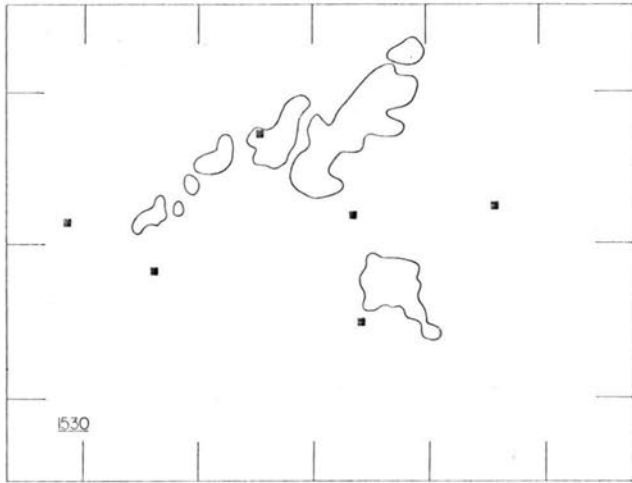
1. Denver, 0500 MST.



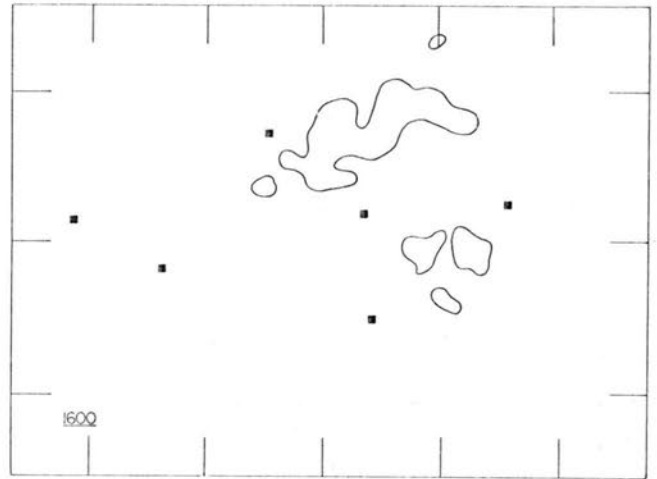
2. Denver, 1700 MST.

30 July 1962
Radar Echo Positions

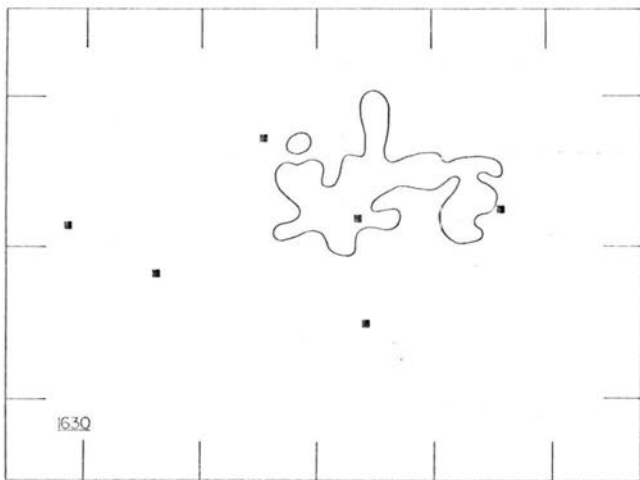
Figure I



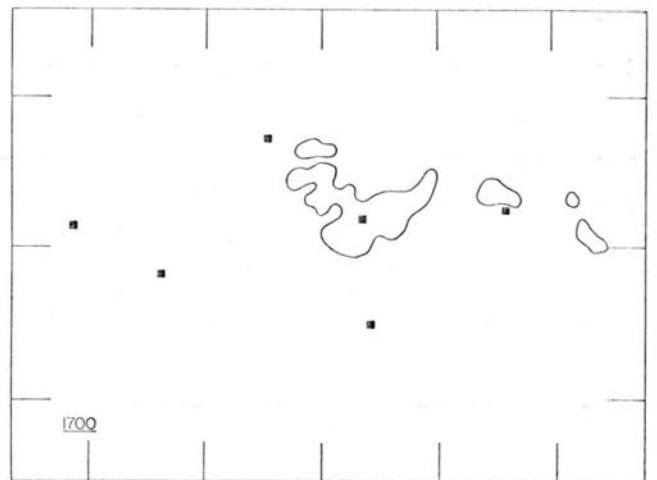
1.



2.



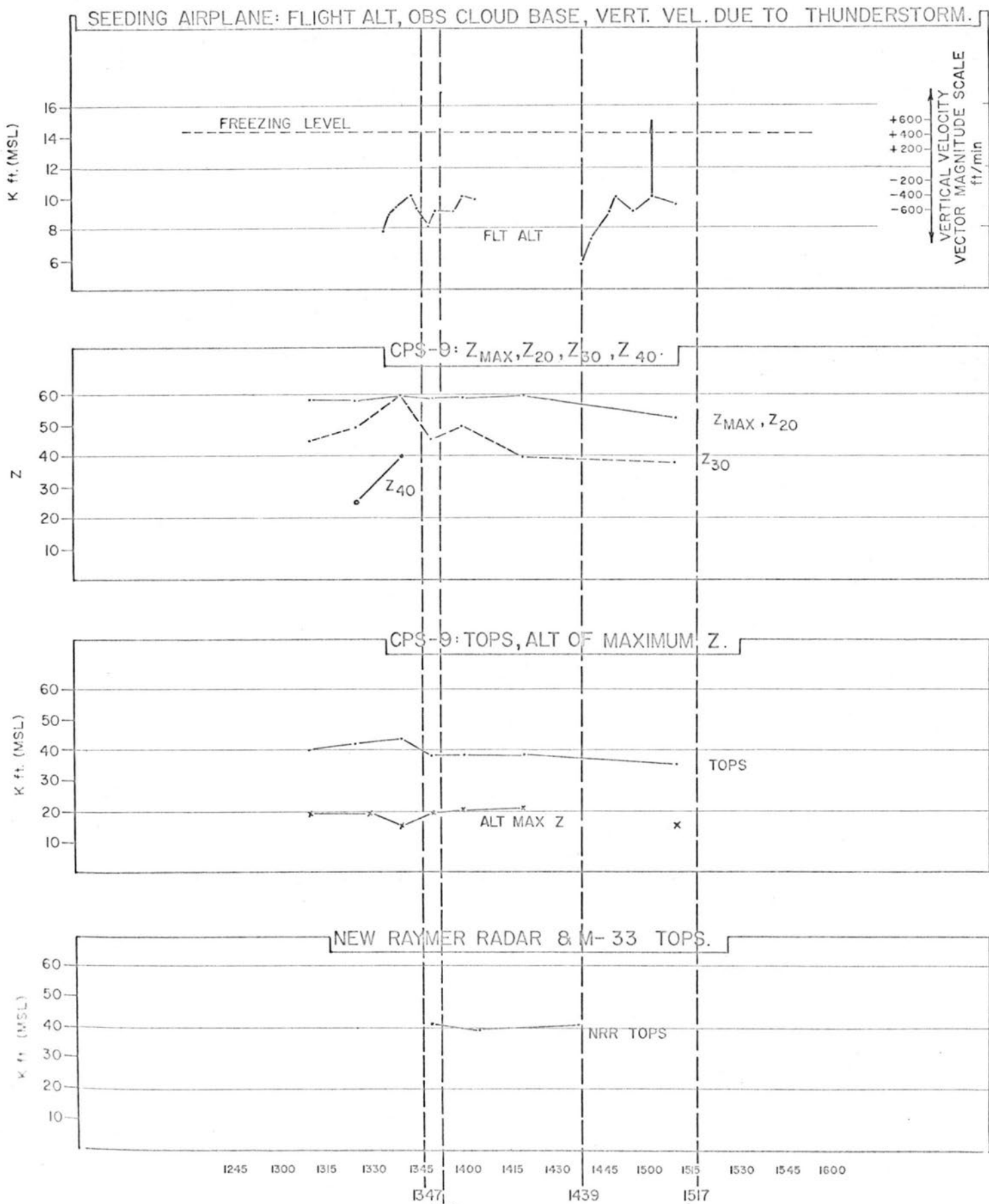
3.



4.

30 JULY-1962

FIGURE J



TEST CASE #3 OF 31 JULY 1962

Test Case Began 1524 MST, Ended 1600 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 30 gms/min. Equipment Used: C. S. U. Generator

SUMMARY TABLE

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	NA	0	NA	0
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	NA	0	NA	0
Area covered by radar echo, mi ²	238	1	NA	0	261	1
Rainfall-volume, acre-feet	12.4		18.2		25.5	
Maximum updraft, ft/min.	NA	0	NA	0	NA	0

TEST CASE #4 OF 31 JULY 1962

Test Case Began 1653 MST, Ended 1830 MST

Seeded: YES Material Used: Ag I

Rate of Seeding: 30 gms/min. Equipment Used: C. S. U. Generator

Test Case Characteristics	Before Test Case		During Test Case		After Test Case	
	Ave.	No.	Ave.	No.	Ave.	No.
Maximum diameter hail, inches	NA	0	NA	0	NA	0
Maximum energy no., ft-lb/ft ²	NA	0	NA	0	NA	0
Radar tops K-ft MSL, M-33	NA	0	NA	0	NA	0
Radar tops K-ft MSL, CPS-9	NA	0	36,000	2	34,000	1
Radar tops K-ft MSL, NRR	NA	0	NA	0	NA	0
CPS-9 radar reflectivity, Z ₃₀	NA	0	45	2	NA	0
Area covered by radar echo, mi ²	165	1	114	1	NA	0
Rainfall-volume, acre-feet	17.0		19.2		20.3	
Maximum updraft, ft/min.	1,000	1	NA	0	NA	0

SIGNIFICANT FEATURES

The surface weather map on this date shows no significant pressure features. The upper level flow was from the west-northwest, and a weak jet maximum occurred extending from central Colorado to eastern Dakotas.

Silver iodide was released on four separate periods. The first was between 1110 and 1140, when silver iodide was released in a region of developing cumulus clouds north of the New Raymer radar. Test case number two extended from 1432 to 1440 in an area east of Akron, Colorado. Test case number three extended from 1524 to 1600 and was directed at a cell south-southwest of Sterling.

After test case number three, a strong squall line developed north of New Raymer and this was

seeded from 1653 until 1830. This was a strong squall line which passed over the region between New Raymer and Fort Morgan and produced heavy rains. An aircraft reconnaissance was made following this storm to attempt to detect hail falls, and no hail fell in any part of this area.

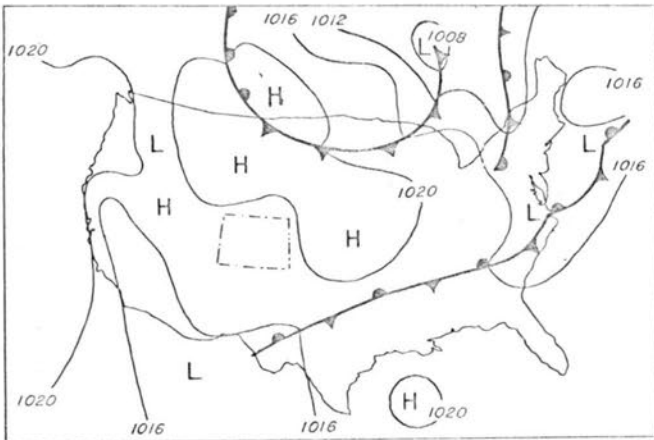
The generator used during these flights was the CSU ammonia, non-combustion silver iodide generator.

There was rain over most of the area but no reported hail in the seeded areas.

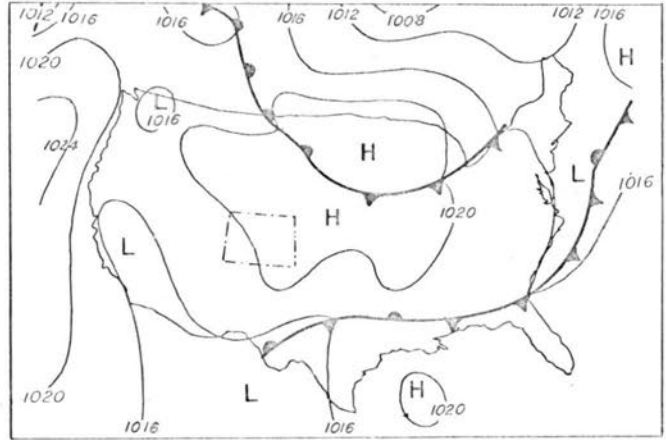
With an observation airplane operating this day, there were many pictures taken that portrayed the local weather situation very well.

31 July 1962
 U.S. Weather Bureau Synoptic Data

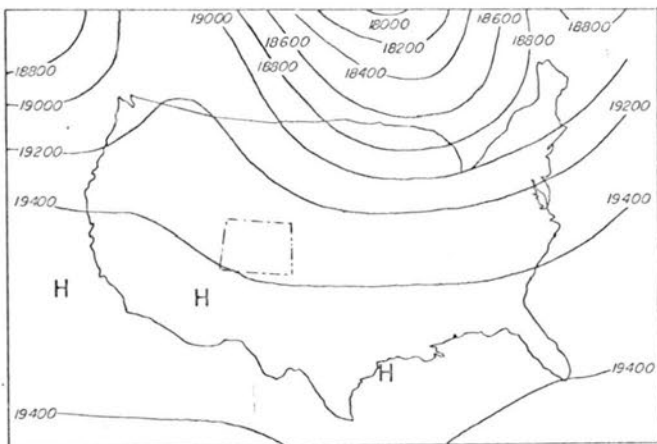
Figures A - F



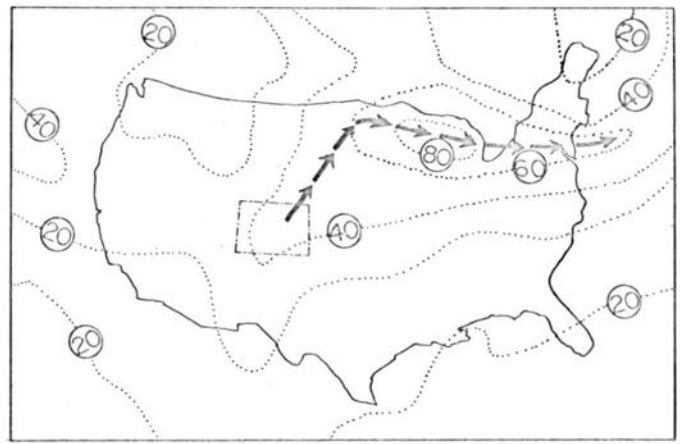
A. Surface Weather Map, 1100 MST (day of test case).



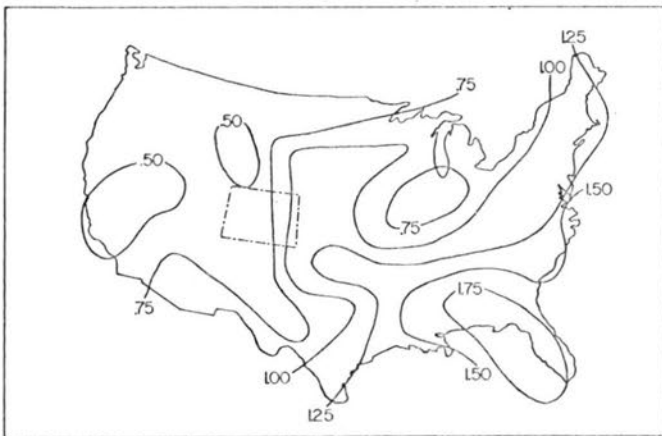
B. Surface Weather Map, 1100 MST (day following test case).



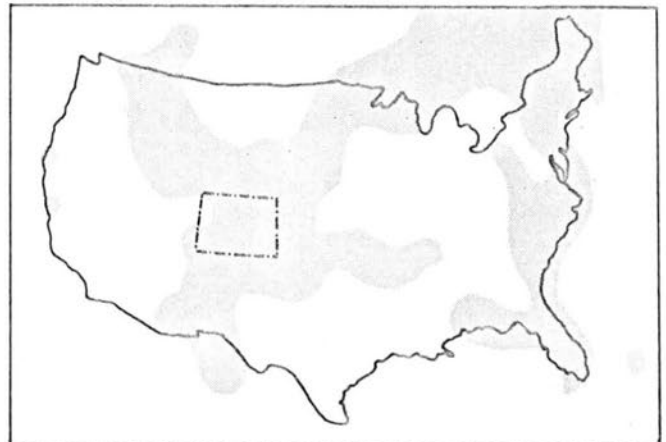
C. 500 mb Map, 1700 MST.



D. 300 mb Jet Streams and Isotachs, Knots, 1700 MST.



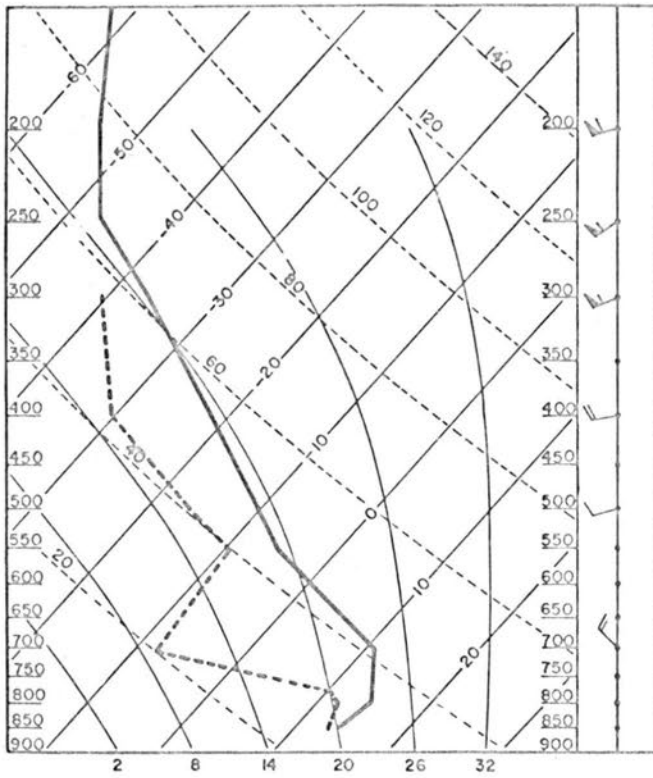
E. Precipitable Water, Inches, 1700 MST.



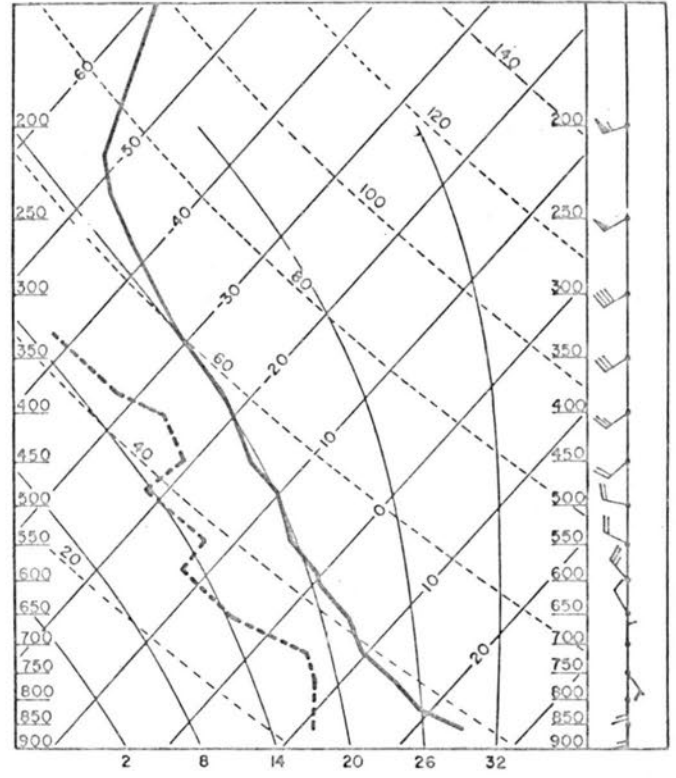
F. Regions of Precipitation for 24-hour Period Ending 2300 MST.

31 July 1962
Upper Air Soundings
Skew-T Diagrams

Figure G



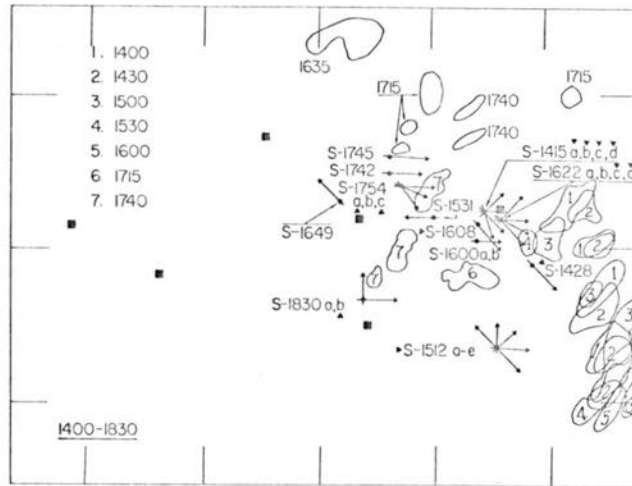
1. Denver, 0500 MST.



2. Denver, 1700 MST.

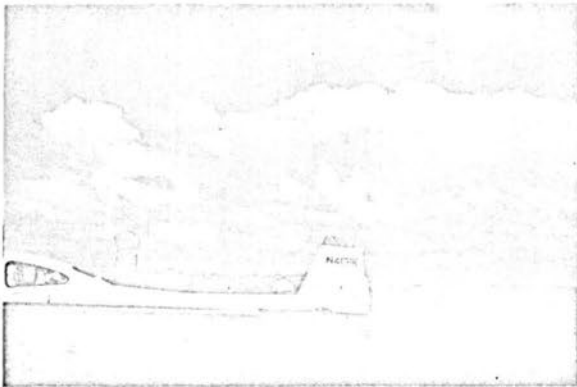
31 July 1962
Photo Index

Figure H



1.

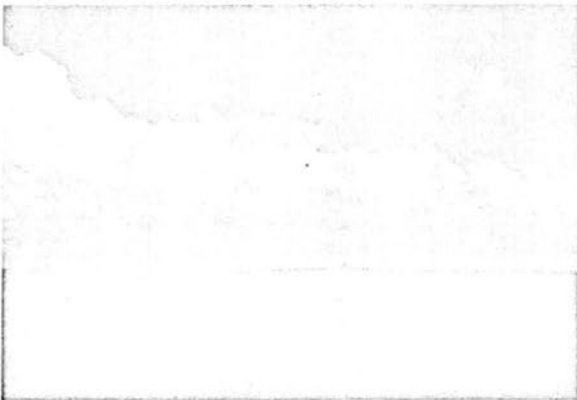
31 July 1962
Selected Photos



S-1415a Test case #2 prior to seeding, looking northeast.



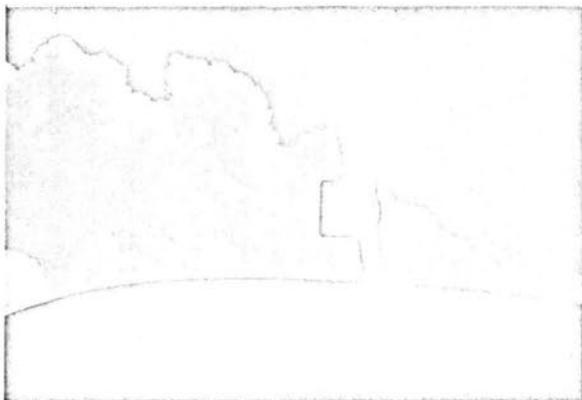
S-1415b Test case #2 prior to seeding, looking east.



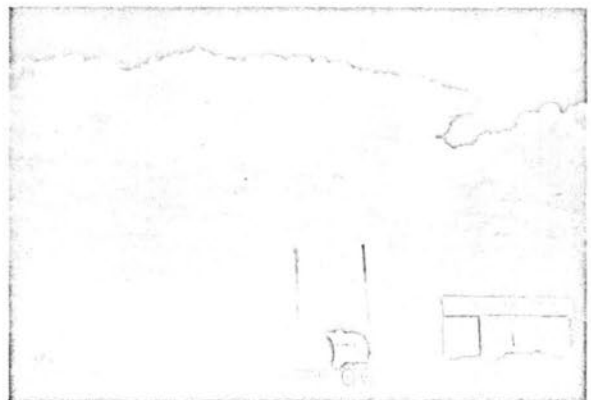
S-1415c Test case #2 prior to seeding, looking southeast.



S-1415d Test case #2 prior to seeding, looking south-southeast.

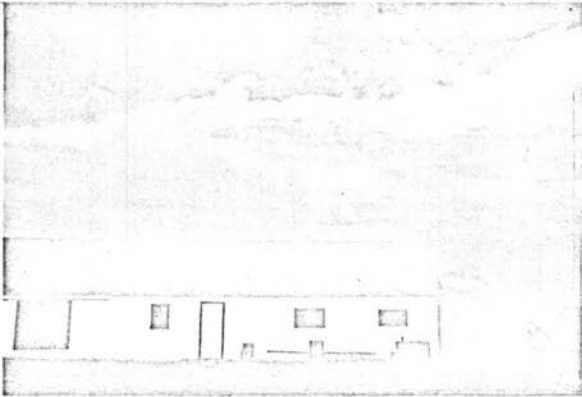


S-1428 Test case #2 from seeding airplane, looking southeast from southeast Sterling.



S-1512a Test case #2 looking southeast from Akron after seeding.

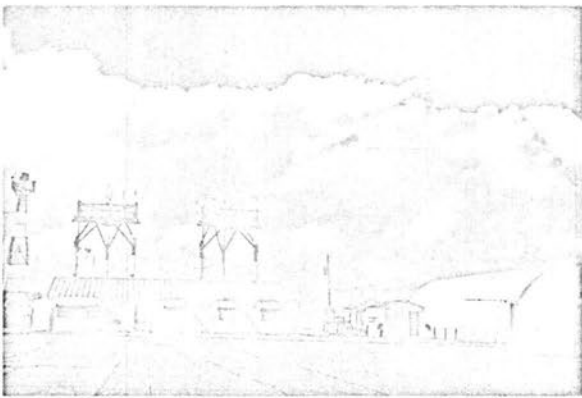
31 July 1962
Selected Photos



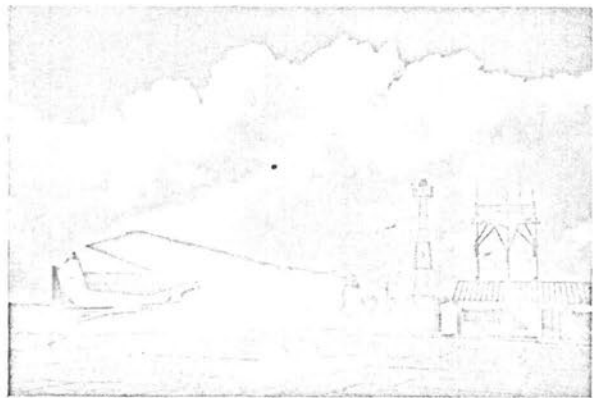
S-1512b Test case #2 looking east from Akron after seeding.



S-1512c Test case #2 looking northeast from Akron after seeding.



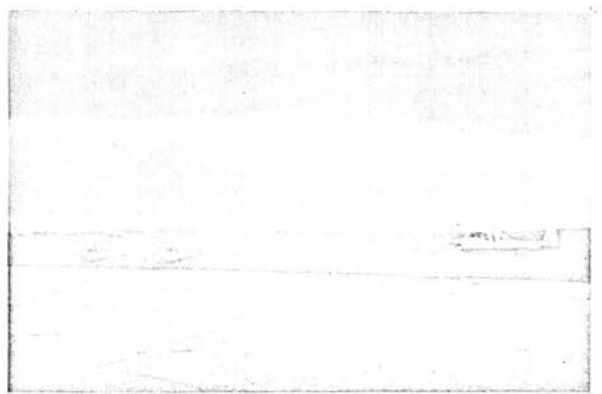
S-1512d Looking north from Akron at an unseeded cell. This is to be test case #3.



S-1512e Looking northwest from Akron at an unseeded cell. This is to be test case #3.



S-1608 Test case #2 and #3 looking southeast from Sterling after seeding.



S-1622c Test case #3 looking east-southeast from Sterling.

31 July 1962
Selected Photos



S-1622d General area of test cases #2 and #3 looking southeast from Sterling.



S-1754a Large cumulus developing southeast of Sterling.



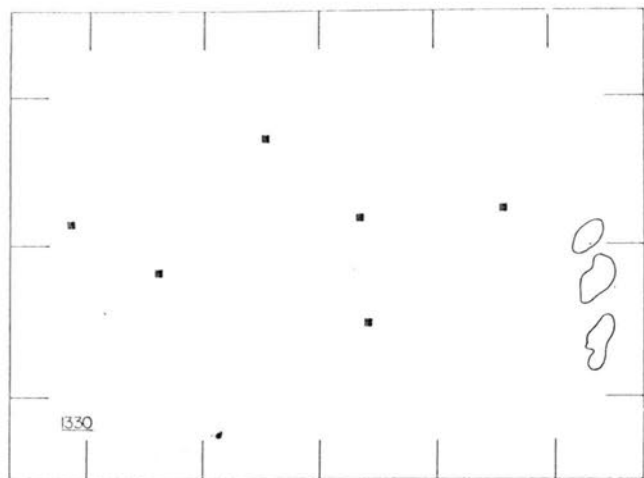
S-1754c Large cumulus west of Sterling. A lot of cumulus activity on this day.



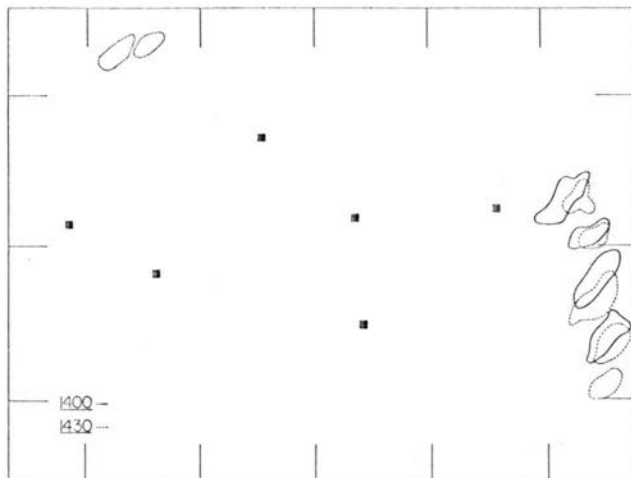
S-1830b Test case #4 looking north from Fort Morgan.

31 July 1962
Radar Echo Positions

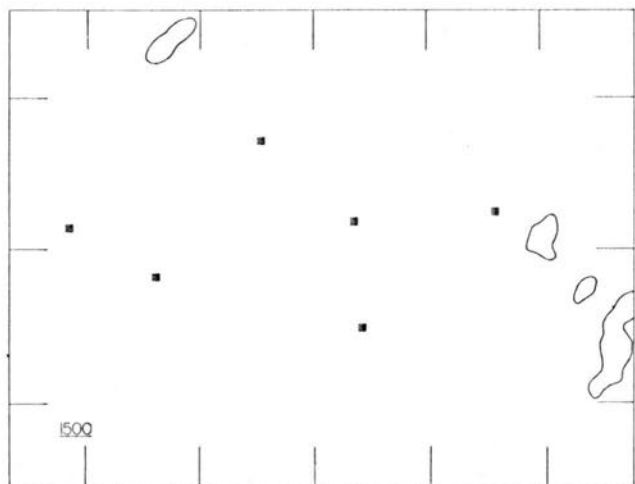
Figure I



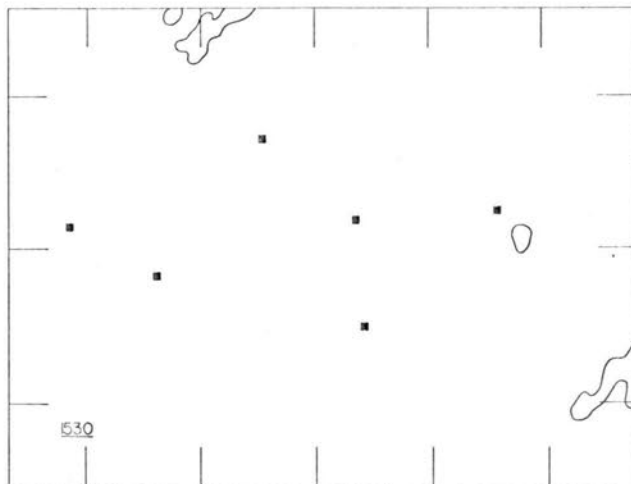
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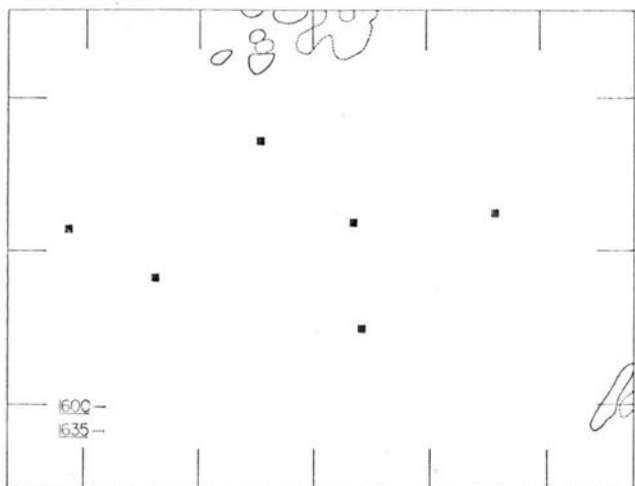
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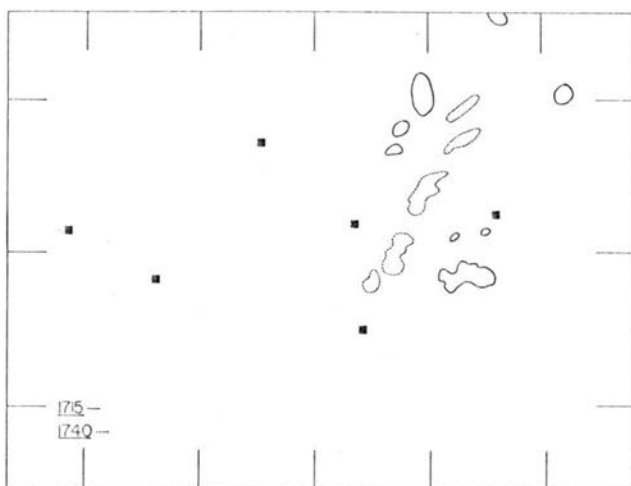
3.



4.



5.



6.

K ft (MSL)

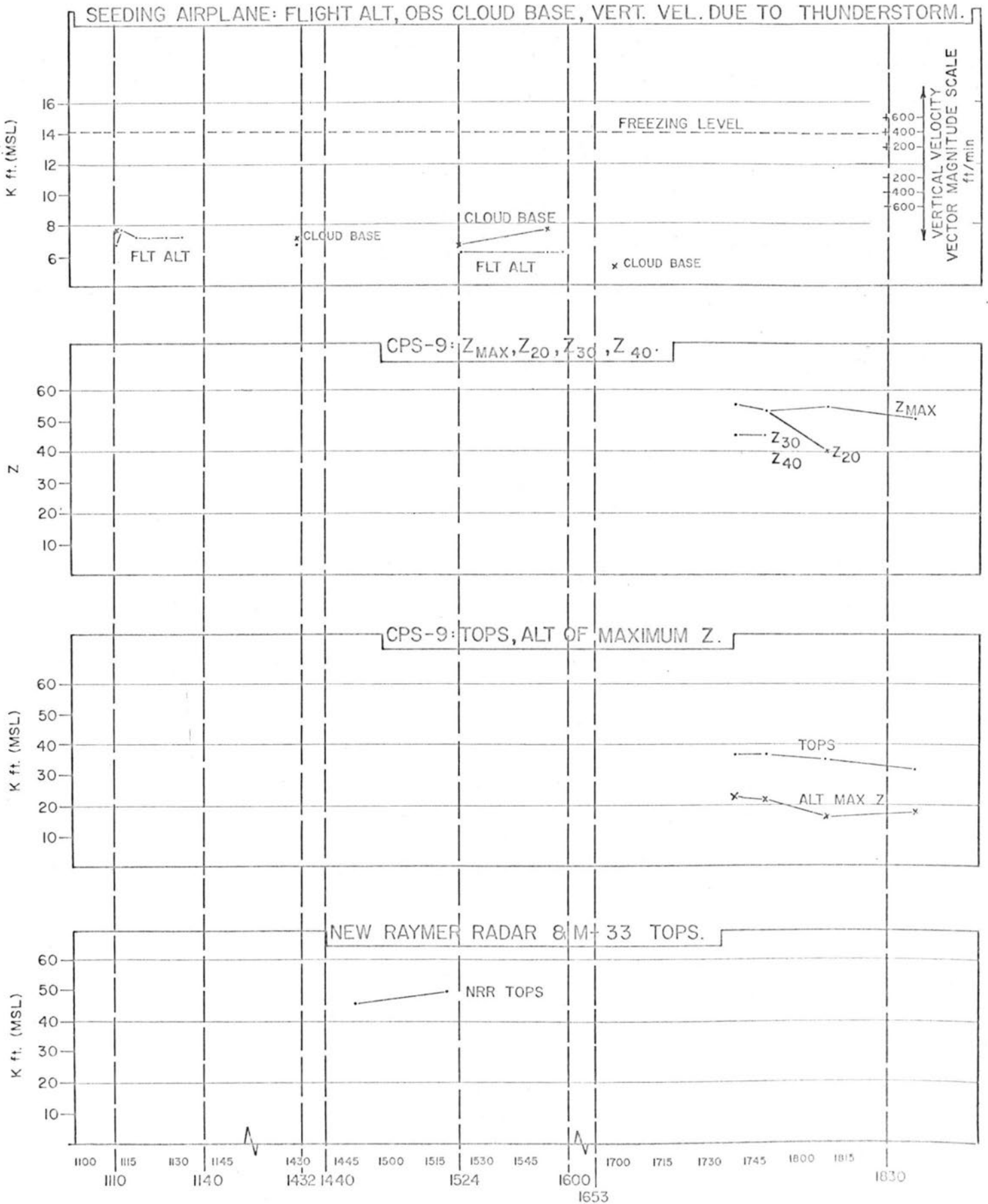
7

K ft (MSL)

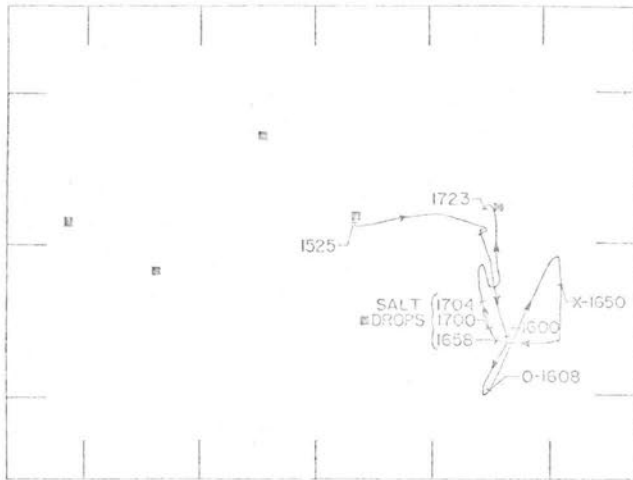
K ft (MSL)

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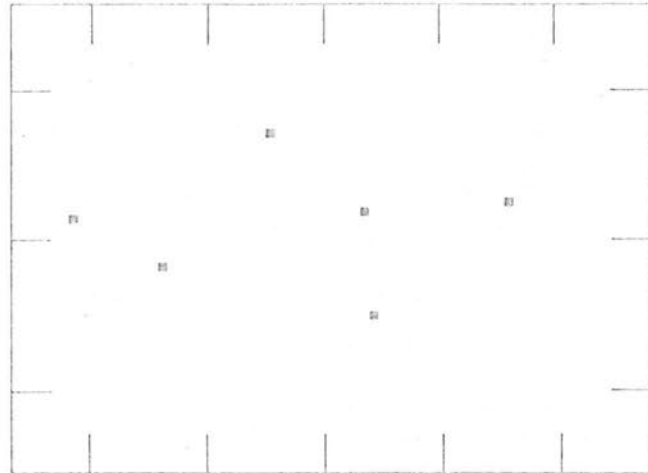
FIGURE J



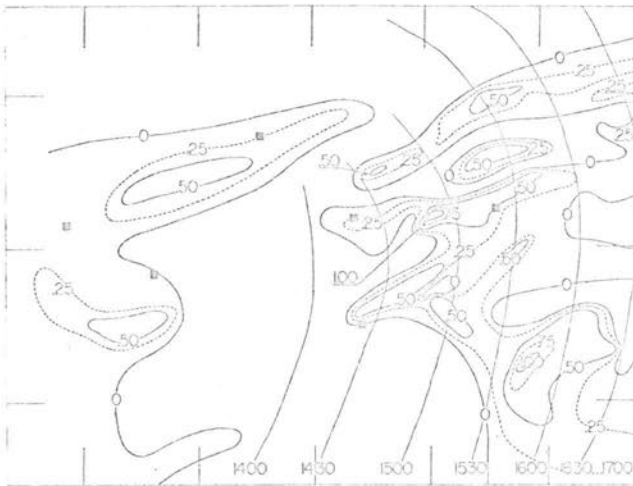
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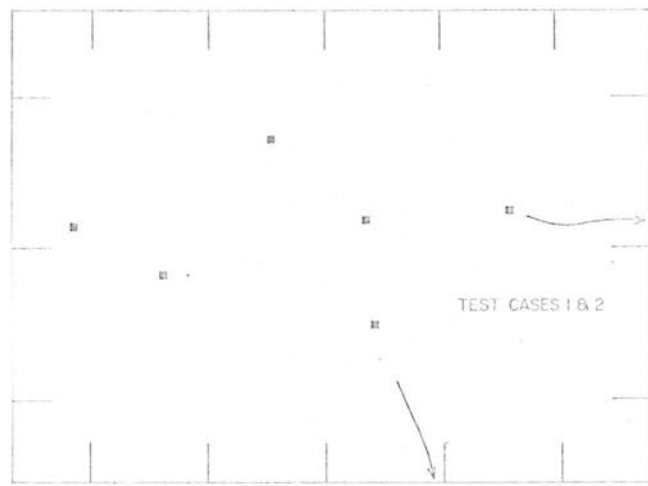
K. Track of Seeding Airplane.



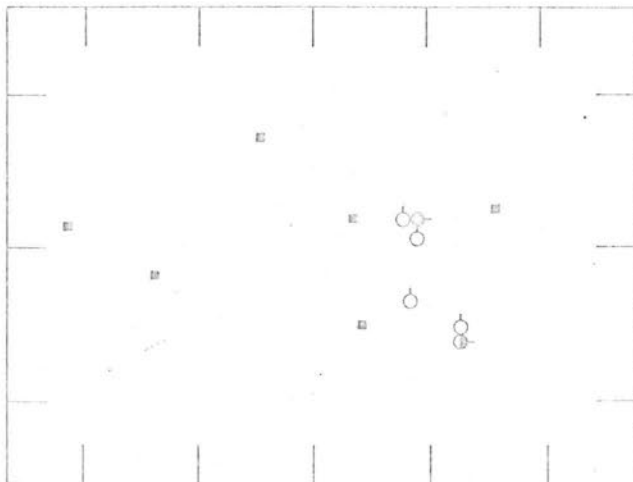
L. Track of Observation Airplane.



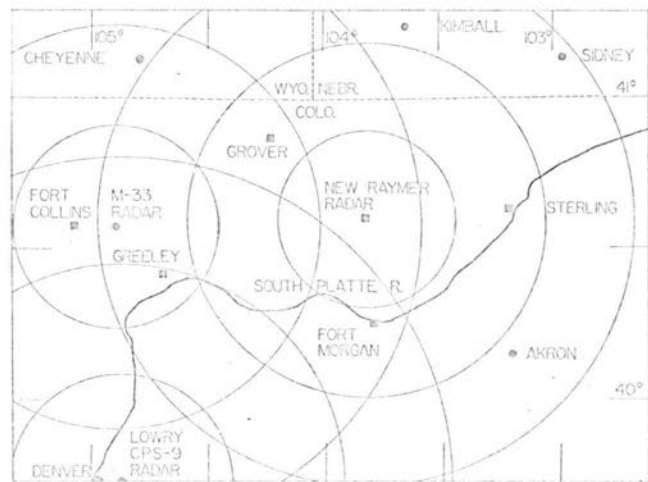
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

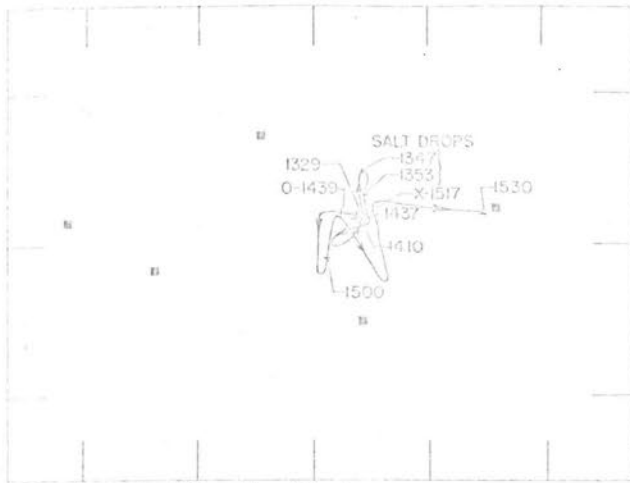


O. Hailfall Reports for a 24-hour Period Ending 2400 MST.

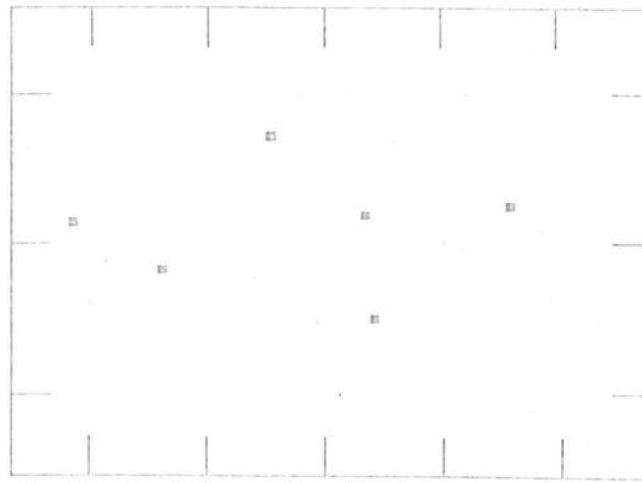


P. Location Identifiers.

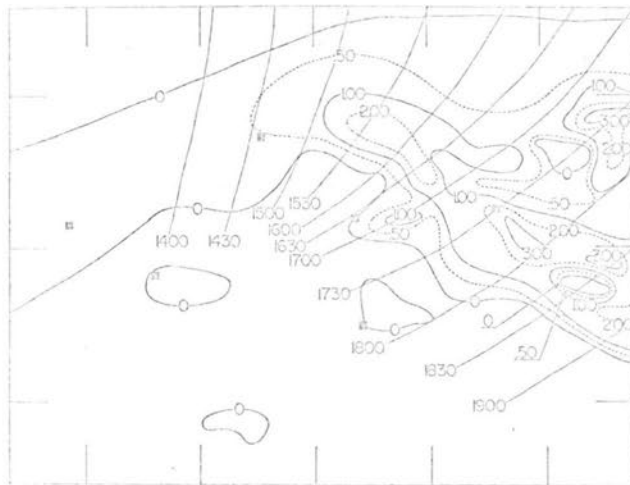
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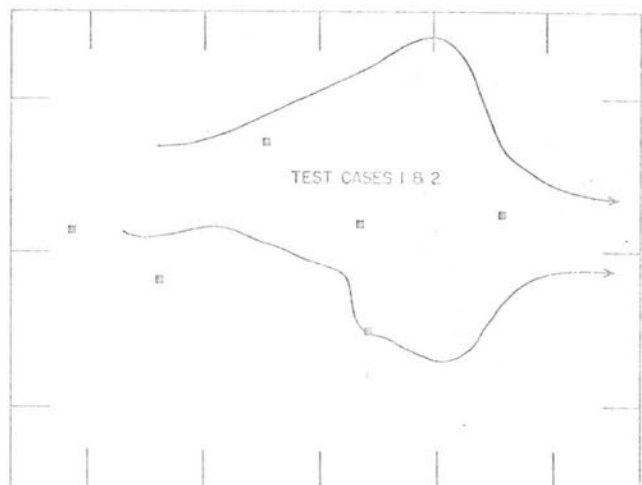
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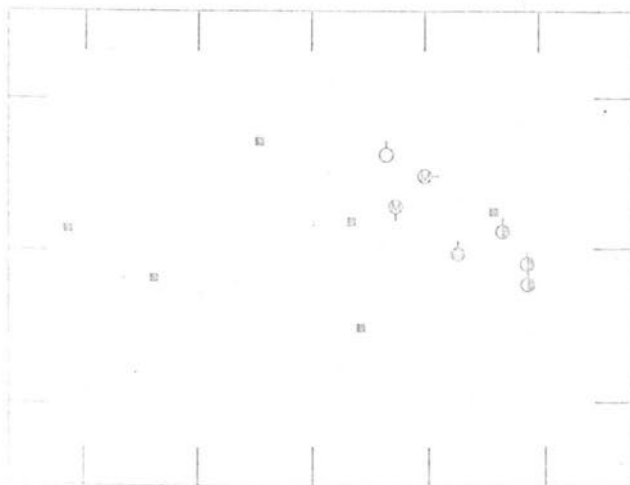
L. Track of Observation Airplane.



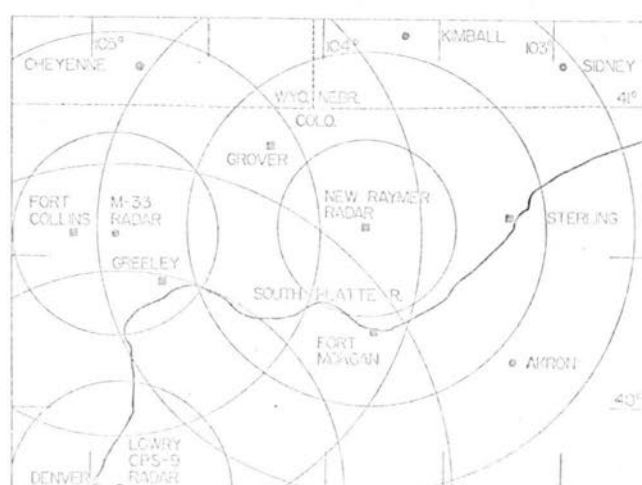
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

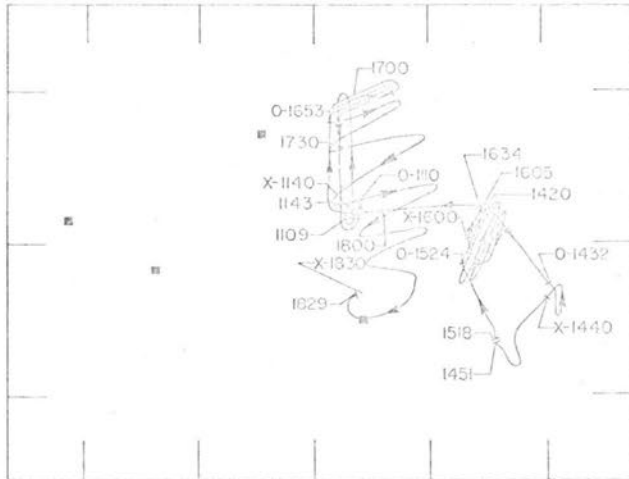


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

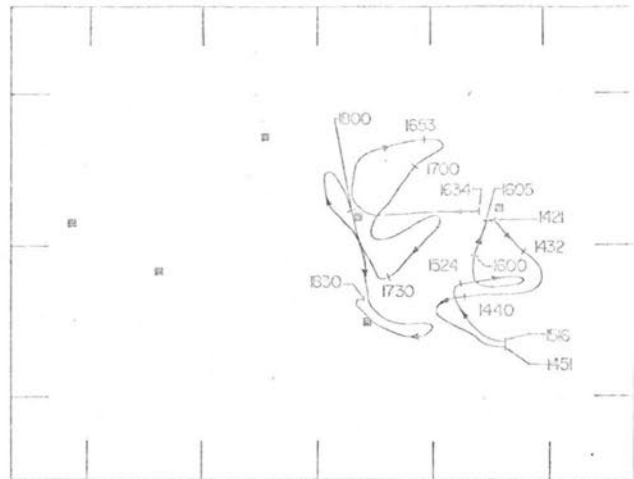


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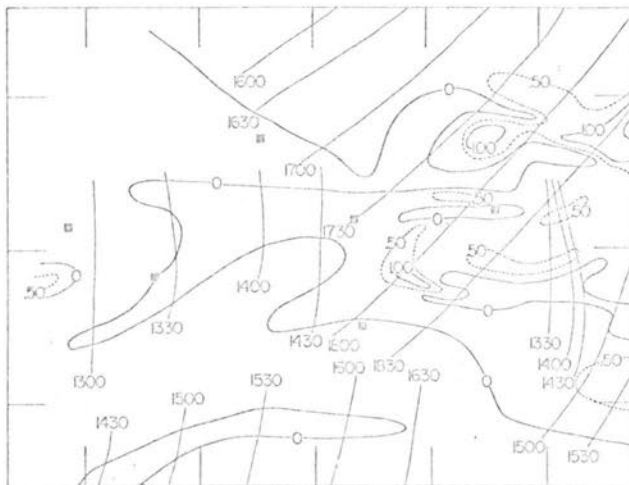
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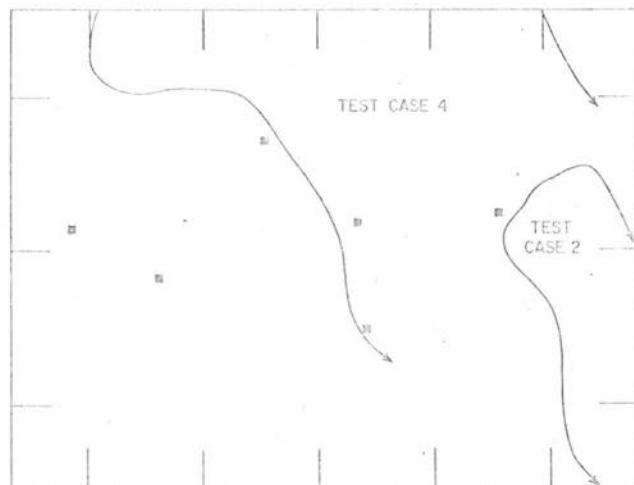
K. Track of Seeding Airplane.



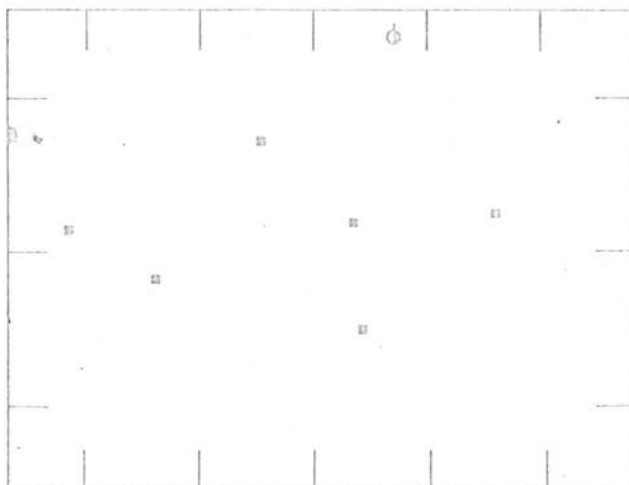
L. Track of Observation Airplane.



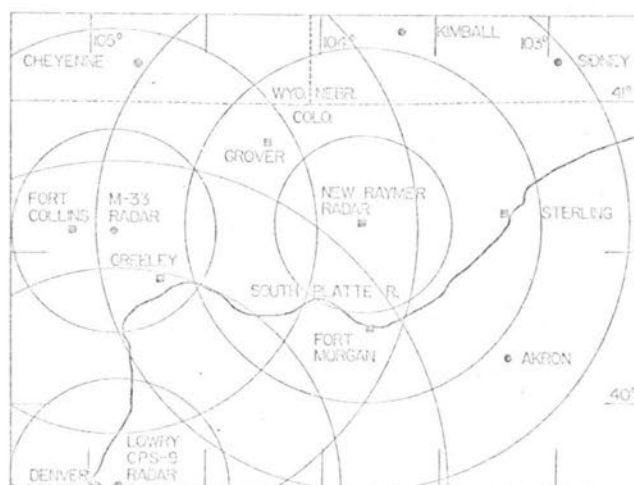
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



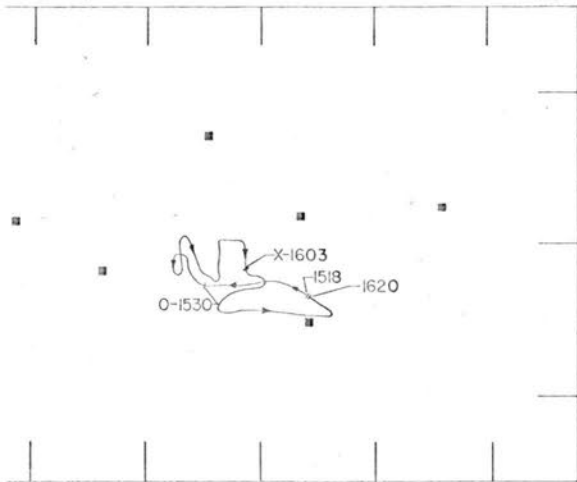
O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



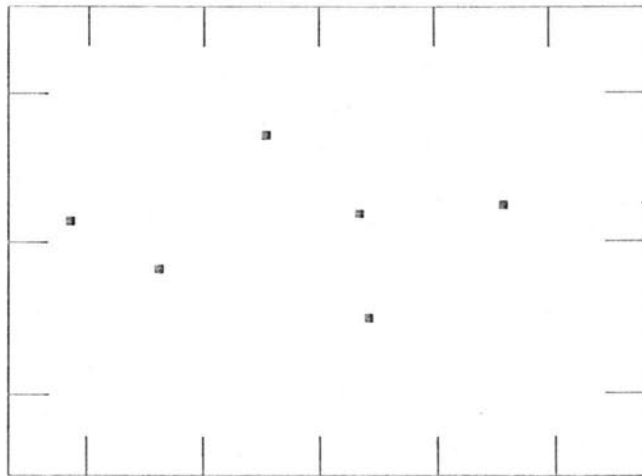
P. Location Identifiers.

15 June 1963

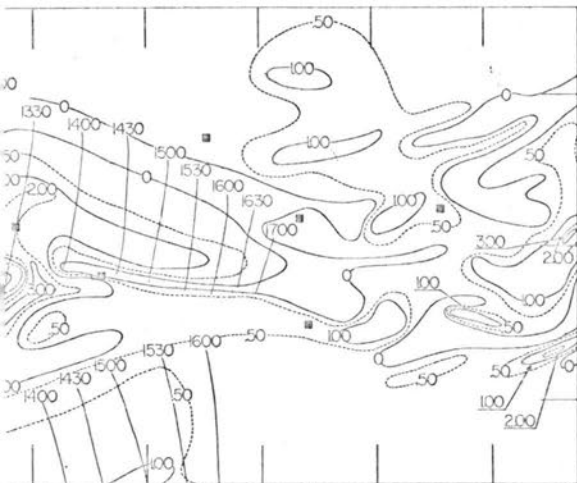
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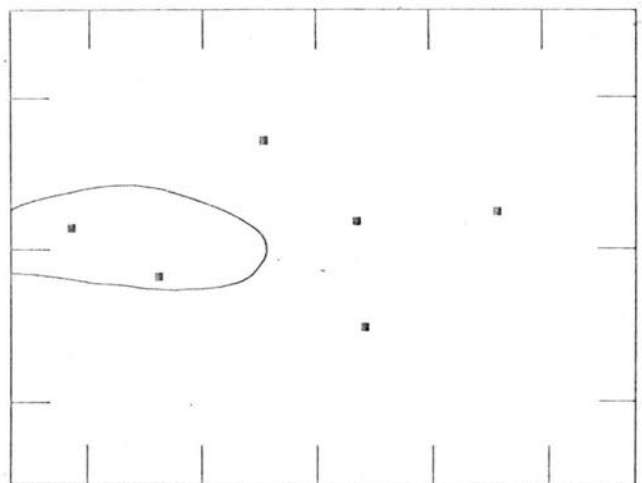
Track of Seeding Airplane.



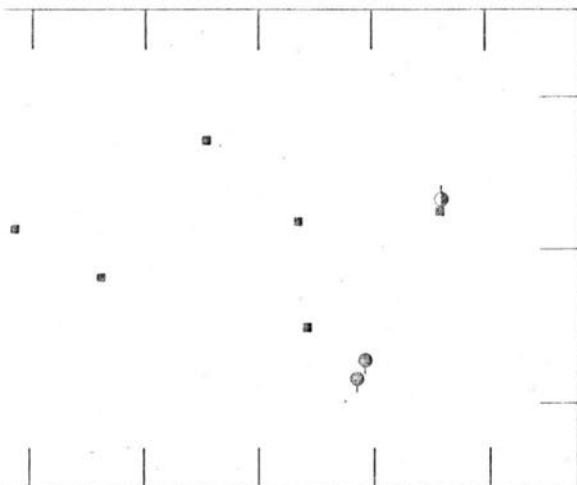
L. Track of Observation Airplane.



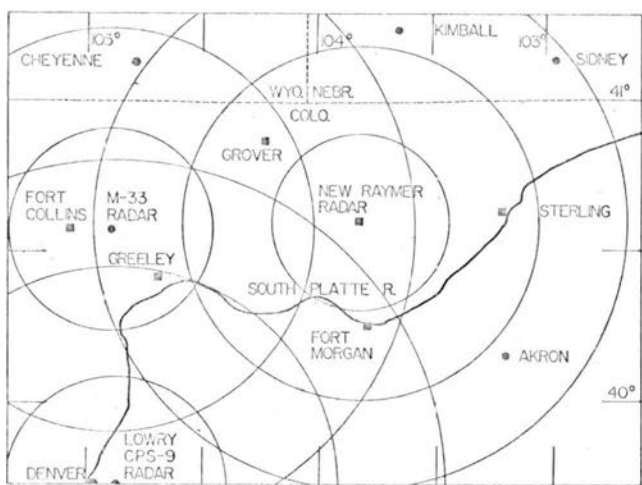
24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



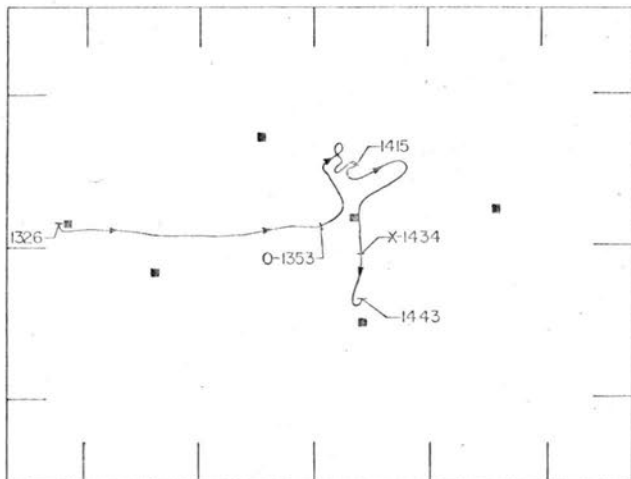
Hailfall Reports for a 24-Hour Period Ending 2400 MST.



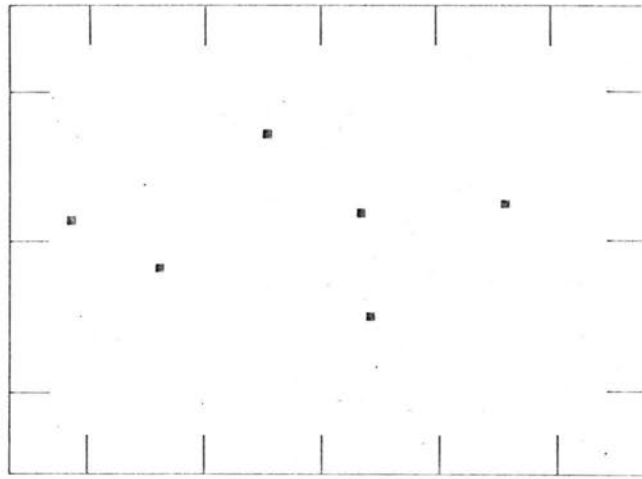
P. Location Identifiers.

11 July 1963

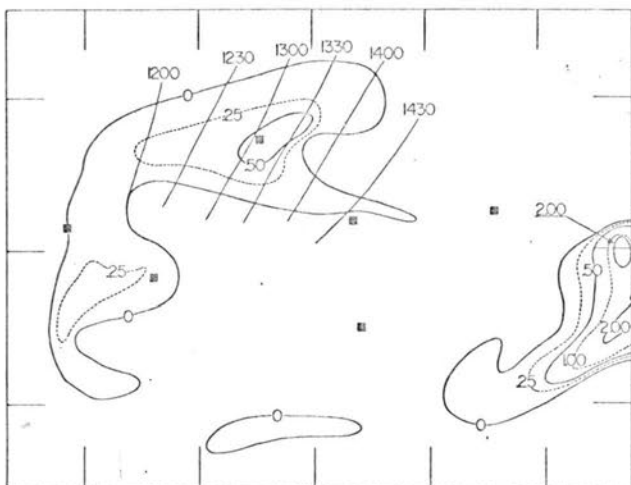
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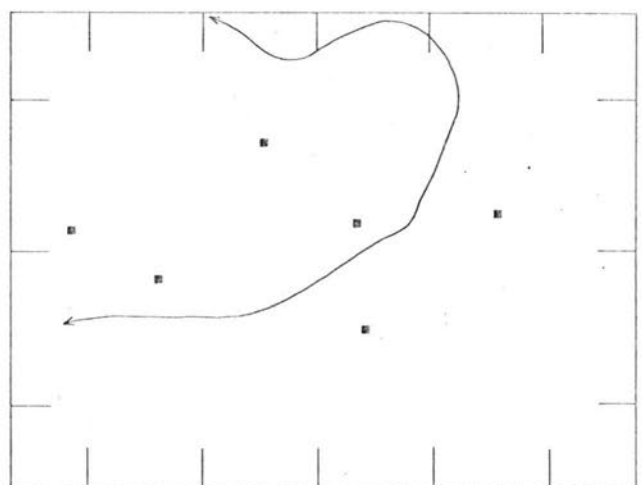
K. Track of Seeding Airplane.



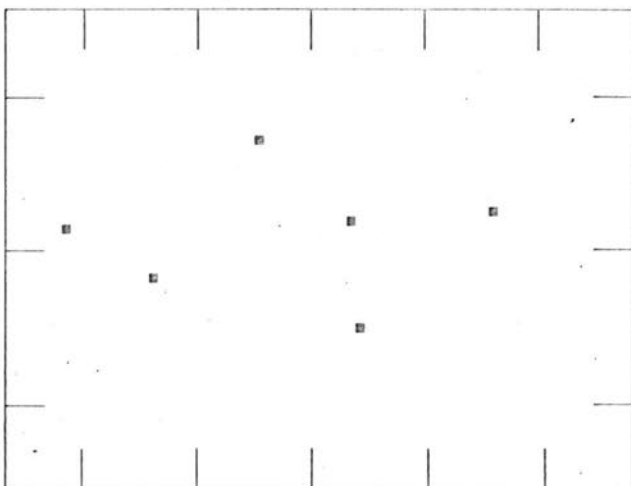
L. Track of Observation Airplane.



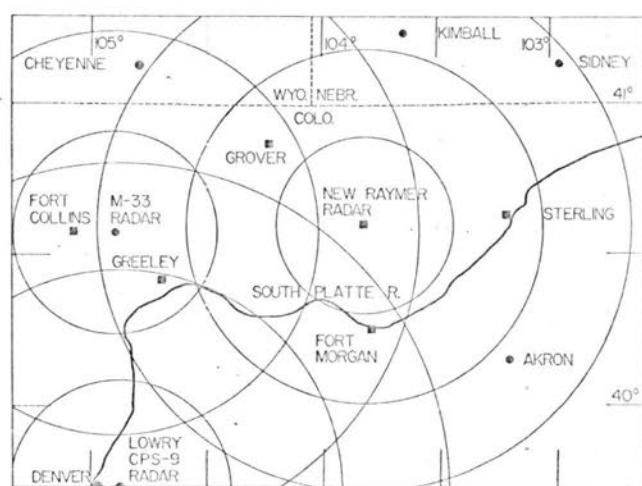
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N. Estimated Limits of Rain and Hail from Test Case.

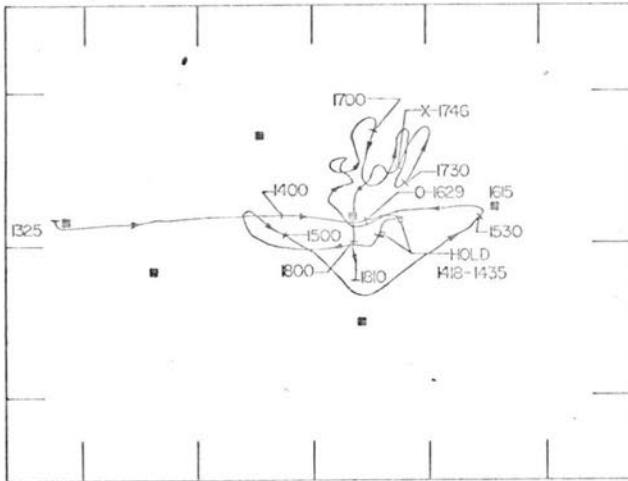


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

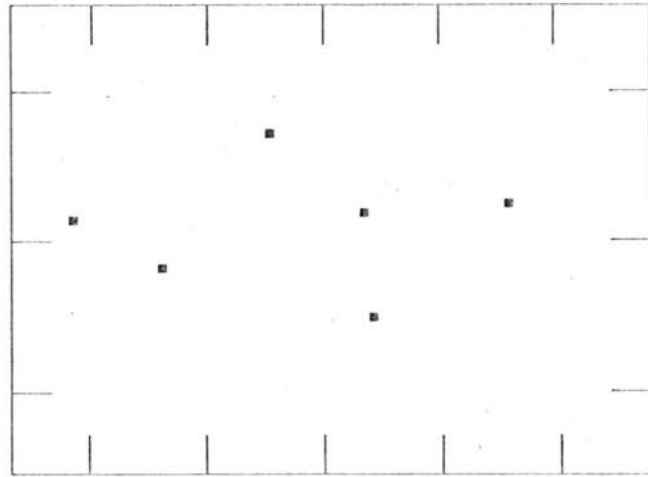


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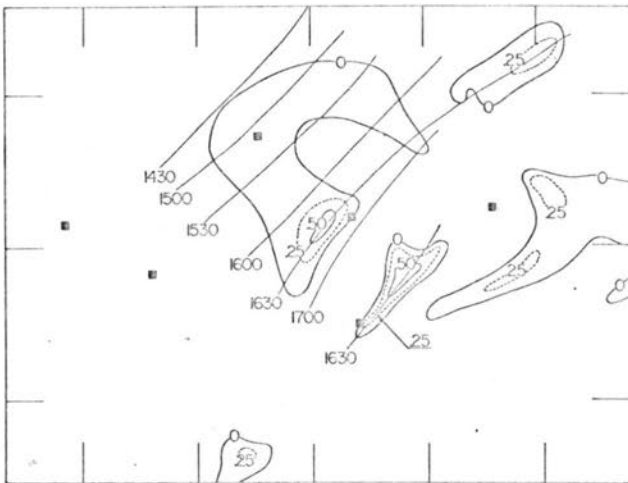
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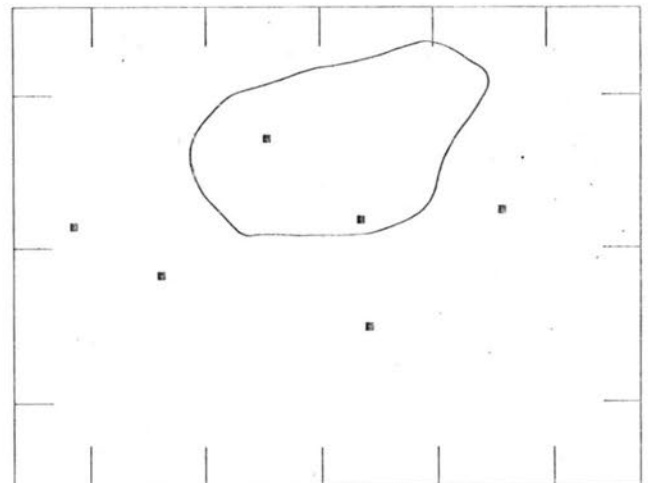
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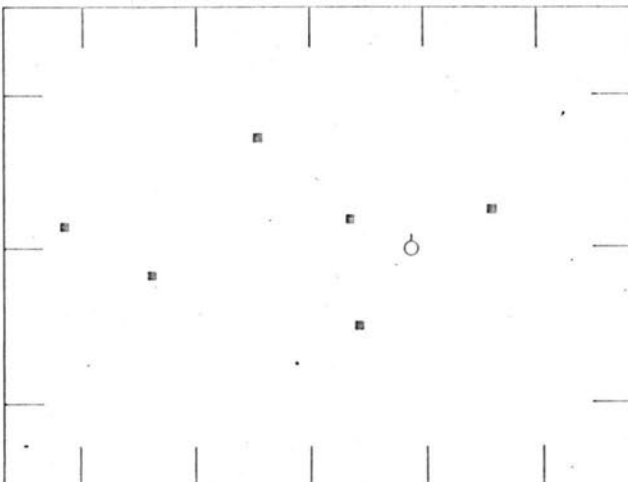
L. Track of Observation Airplane.



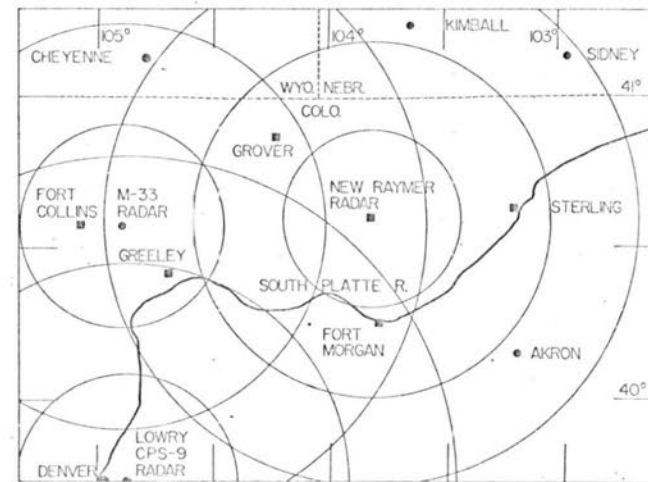
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



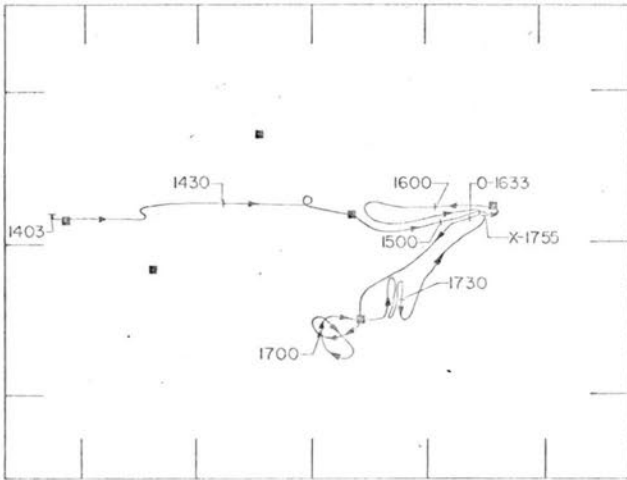
O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



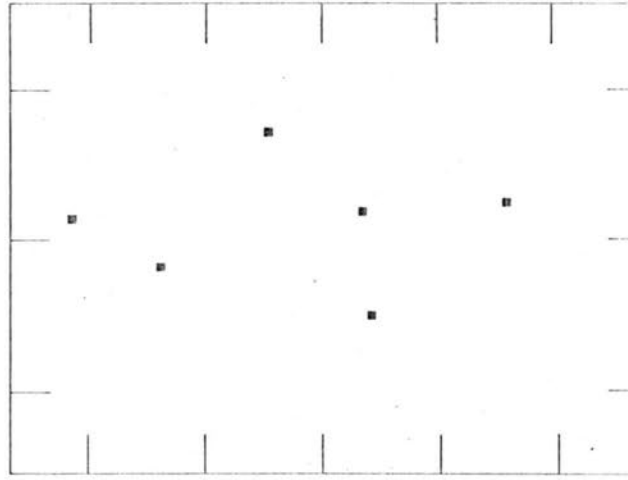
P. Location Identifiers.

22 July 1963

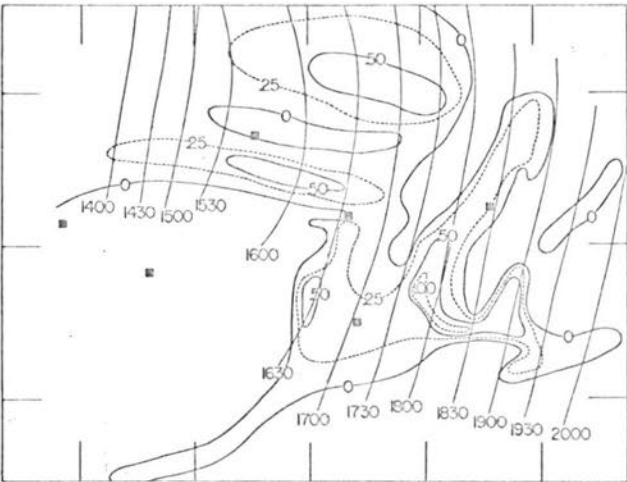
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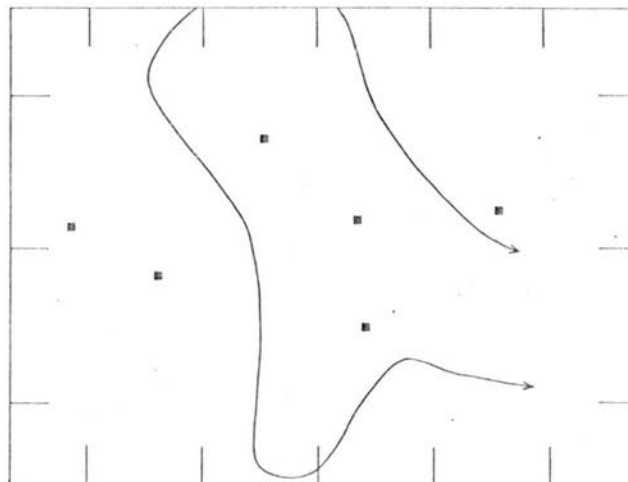
K. Track of Seeding Airplane.



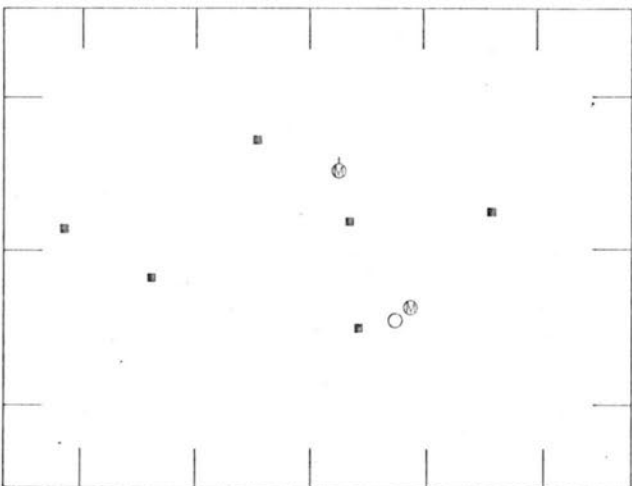
L. Track of Observation Airplane.



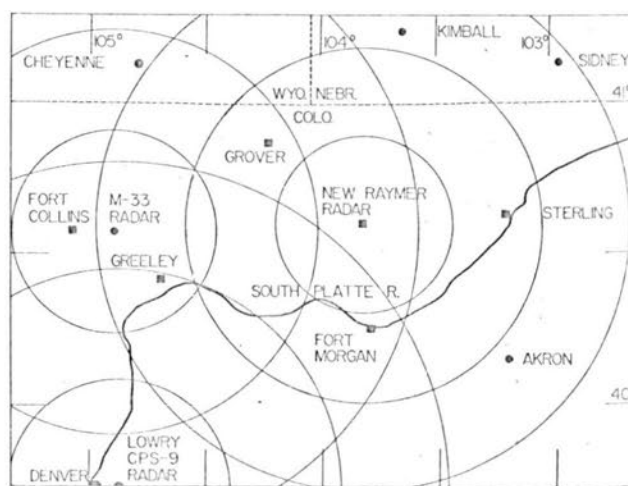
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

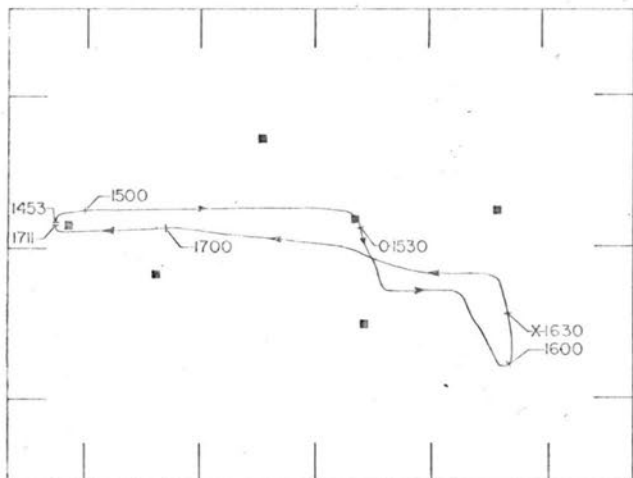


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

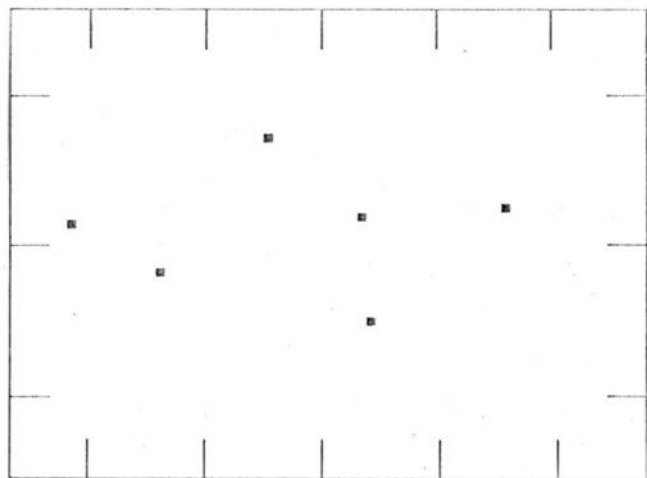


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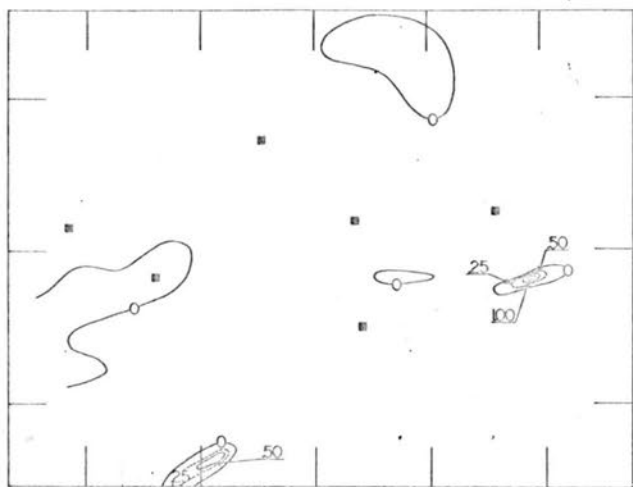
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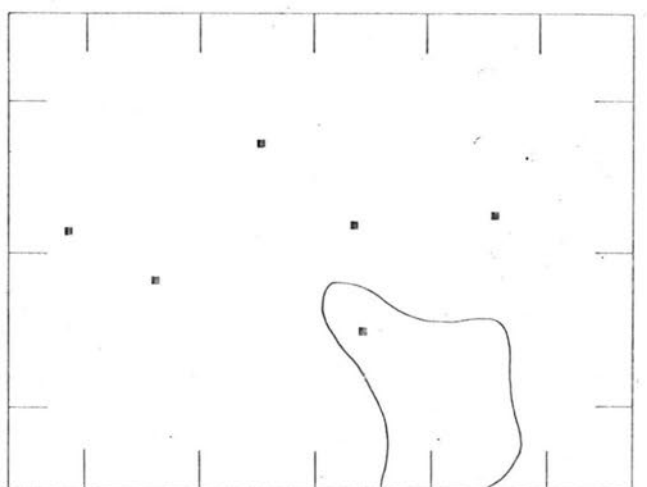
K. Track of Seeding Airplane.



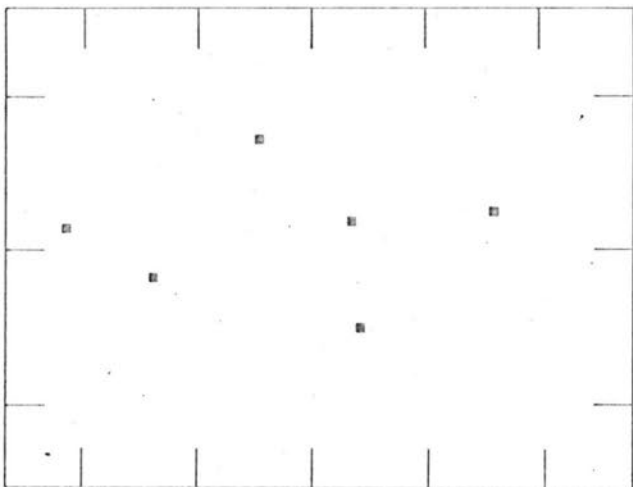
L. Track of Observation Airplane.



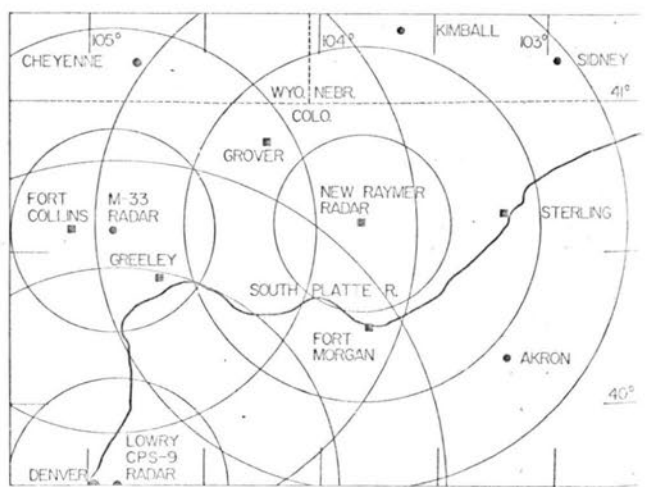
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

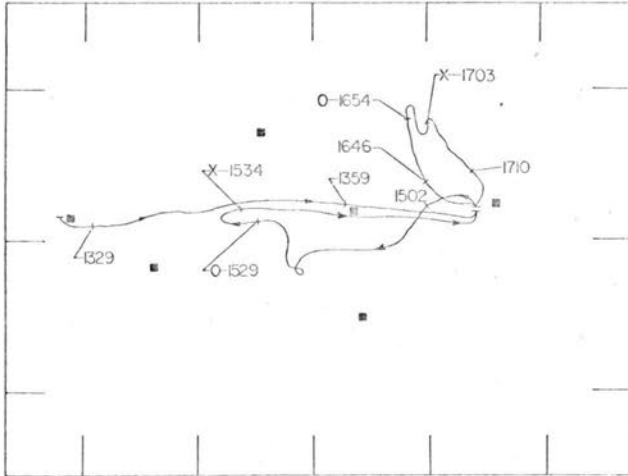


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

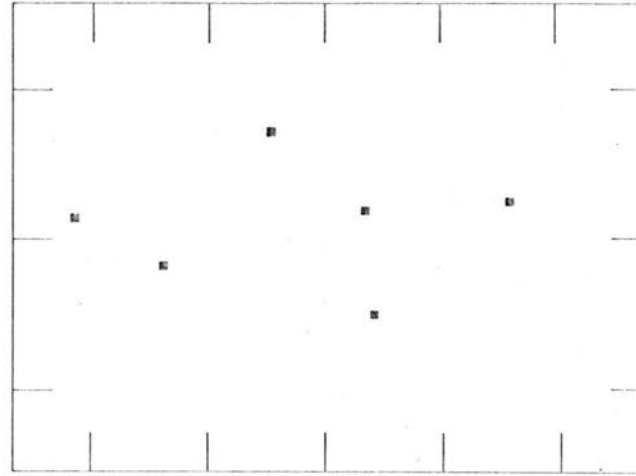


P. Location Identifiers.

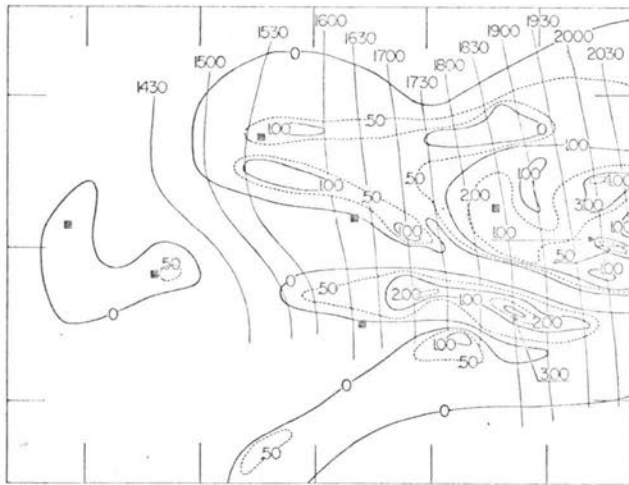
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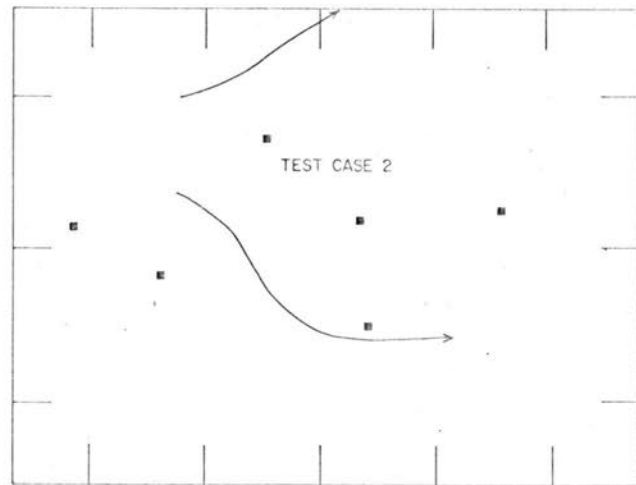
K. Track of Seeding Airplane.



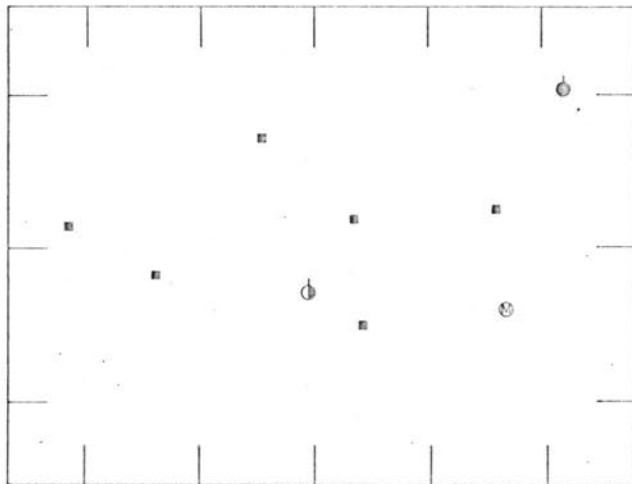
L. Track of Observation Airplane.



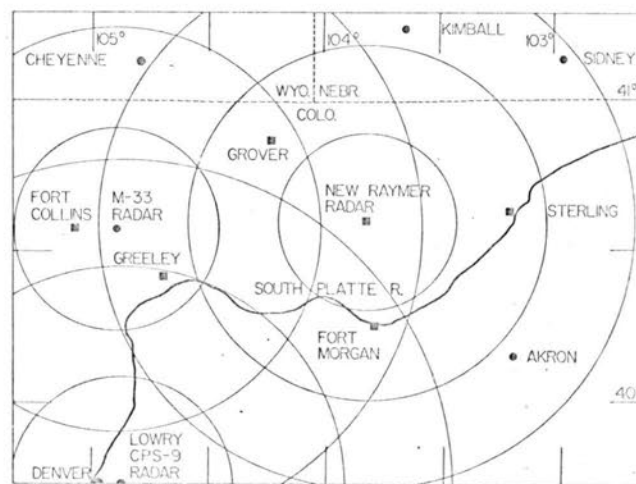
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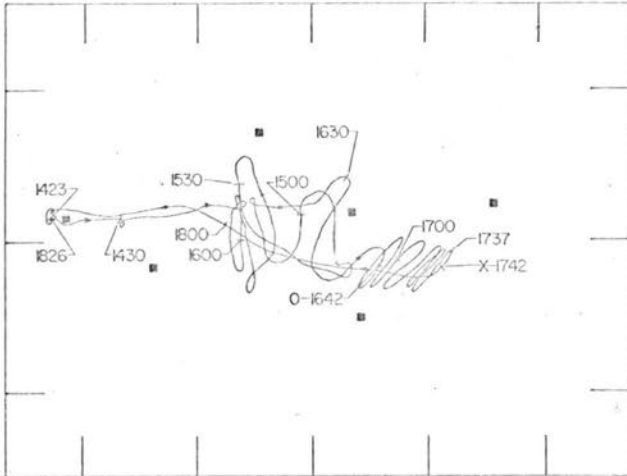
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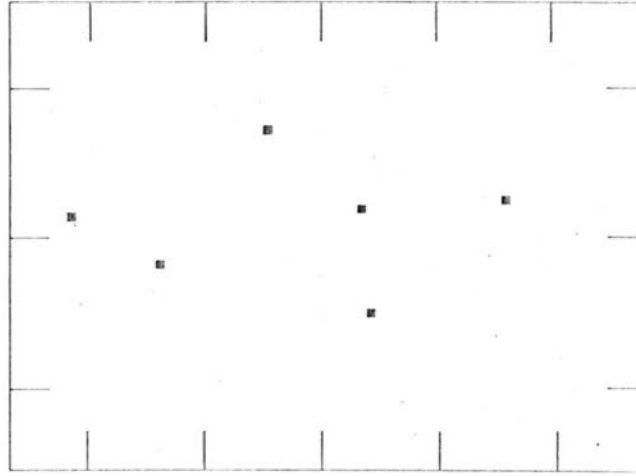
P. Location Identifiers.

6 June 1964

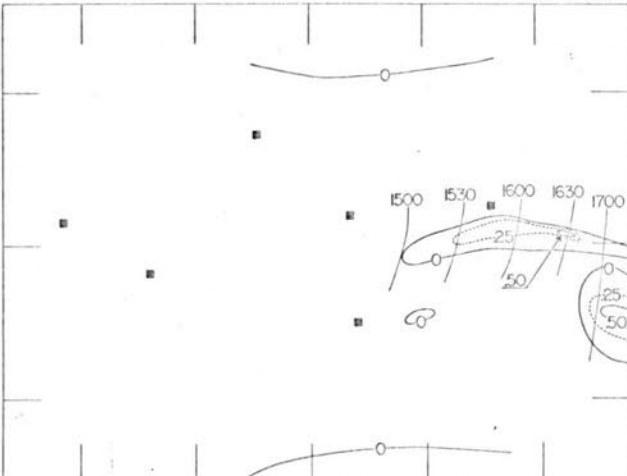
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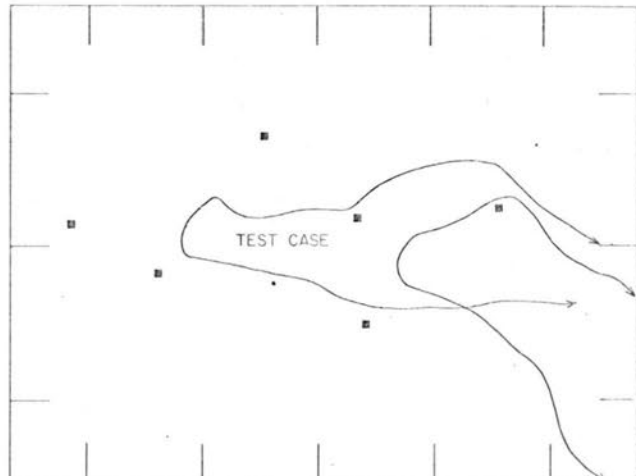
K. Track of Seeding Airplane.



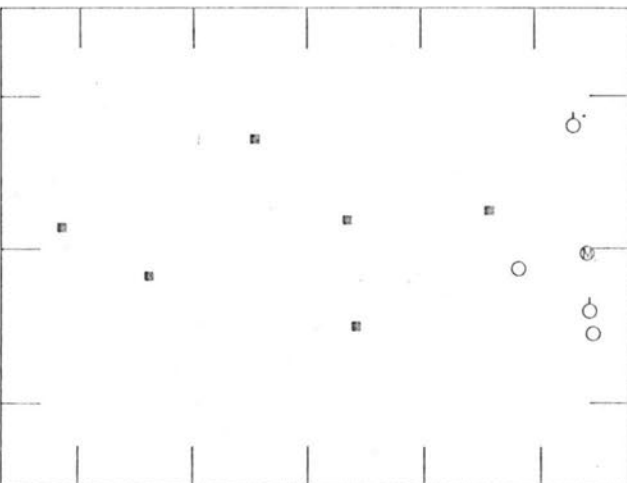
L. Track of Observation Airplane.



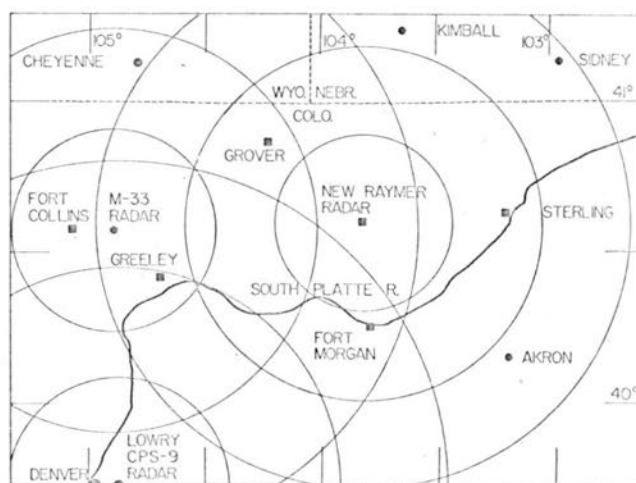
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

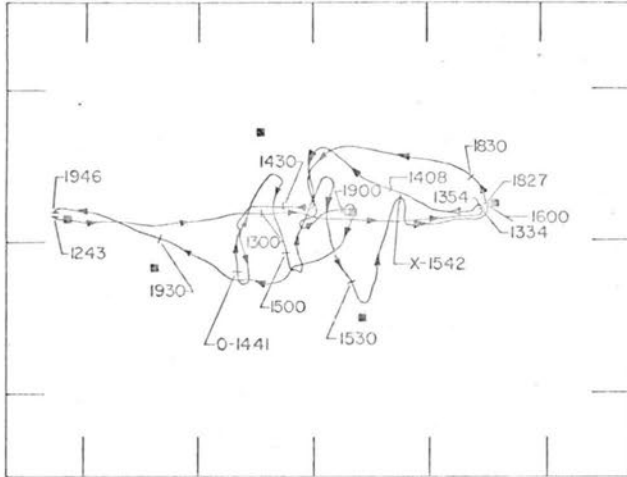


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

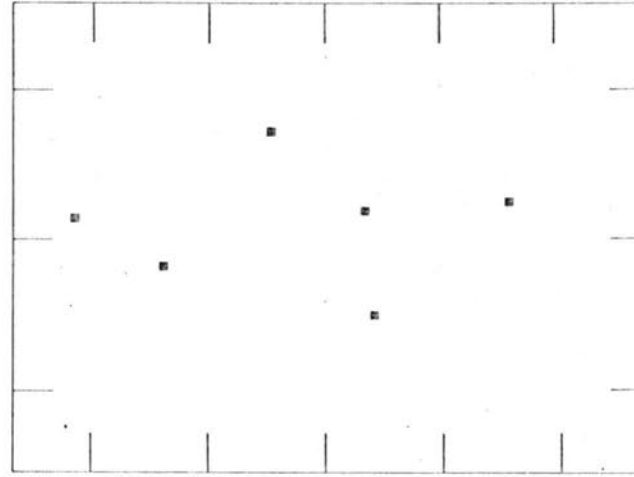


P. Location Identifiers.

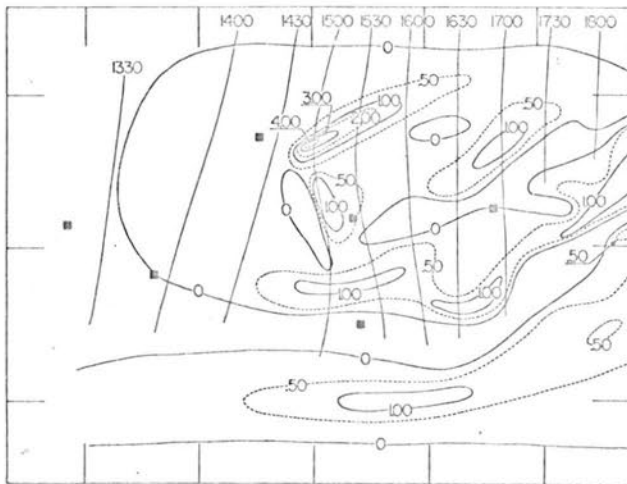
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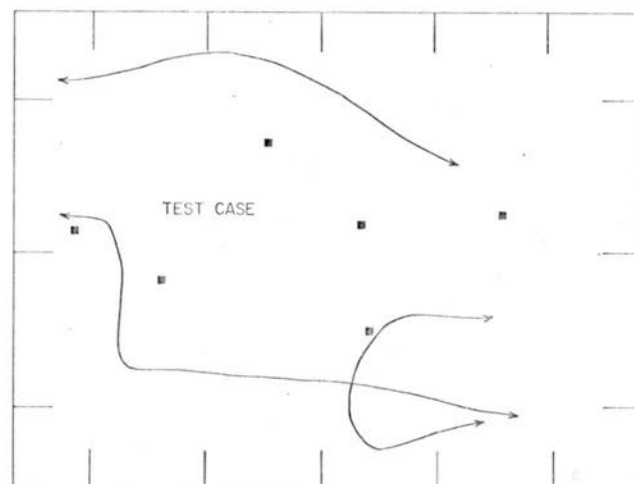
K. Track of Seeding Airplane.



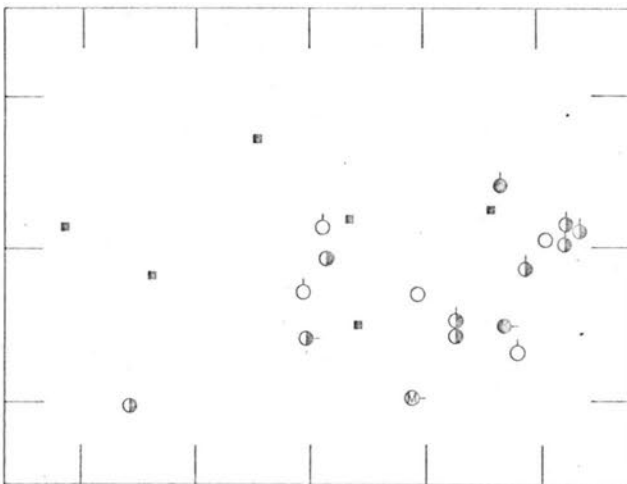
L. Track of Observation Airplane.



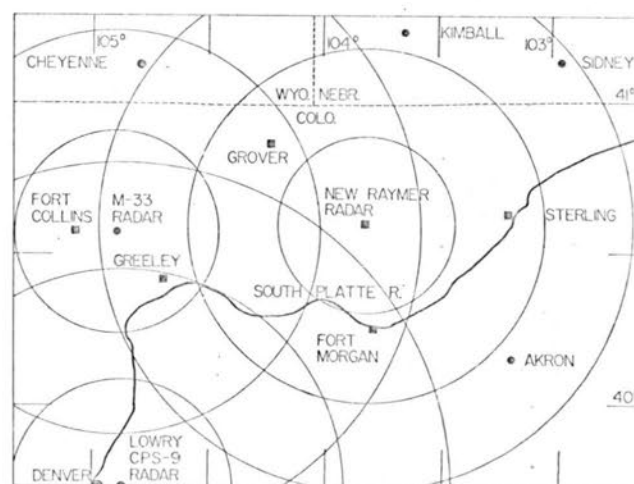
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

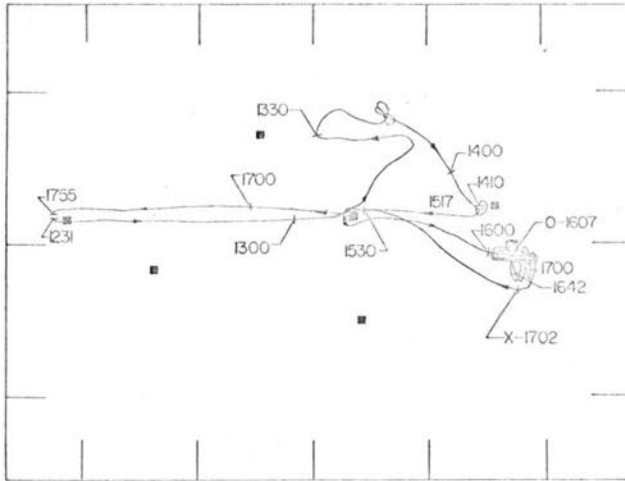


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

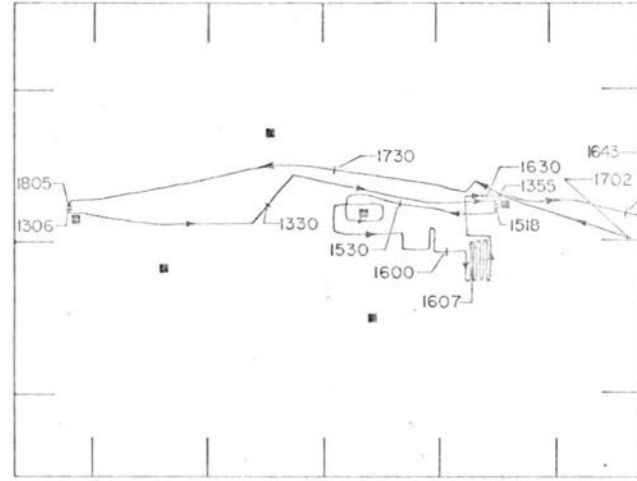


P. Location Identifiers.

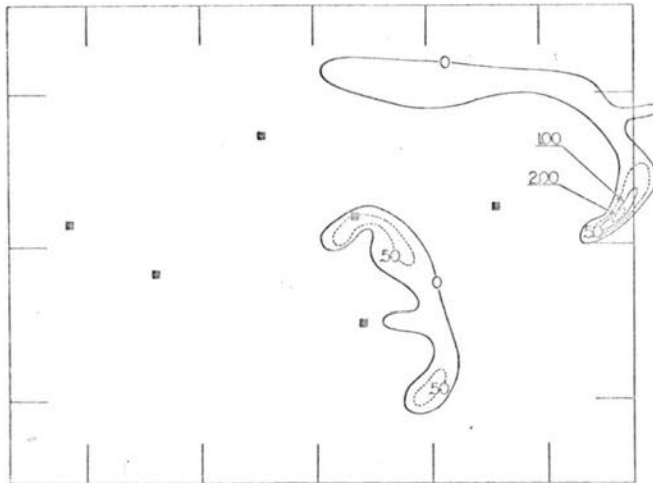
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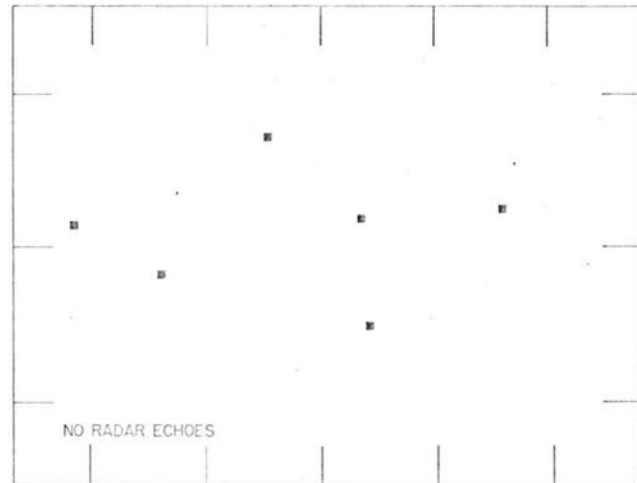
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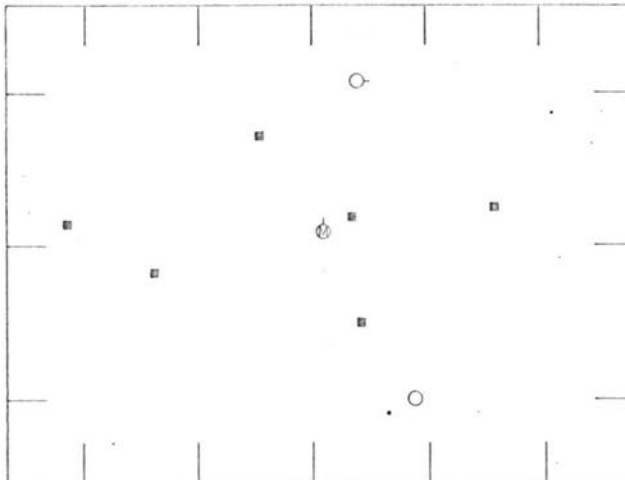
L. Track of Observation Airplane.



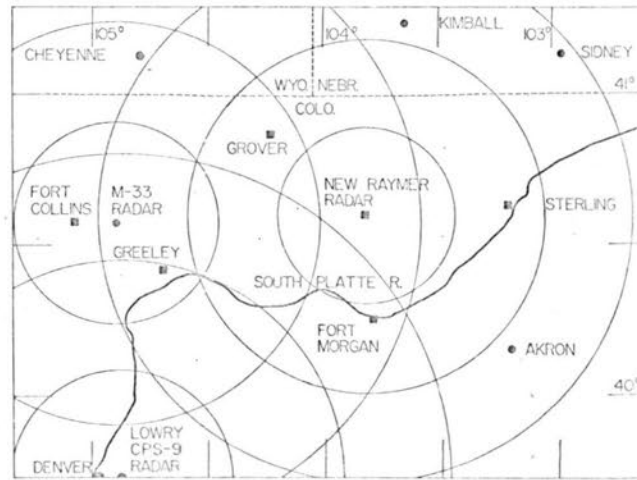
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



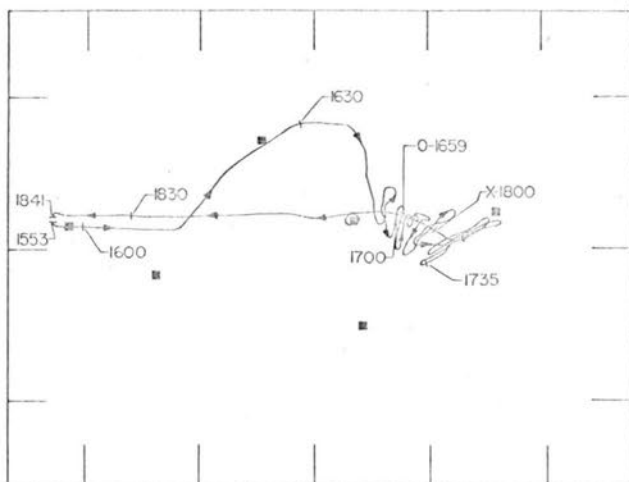
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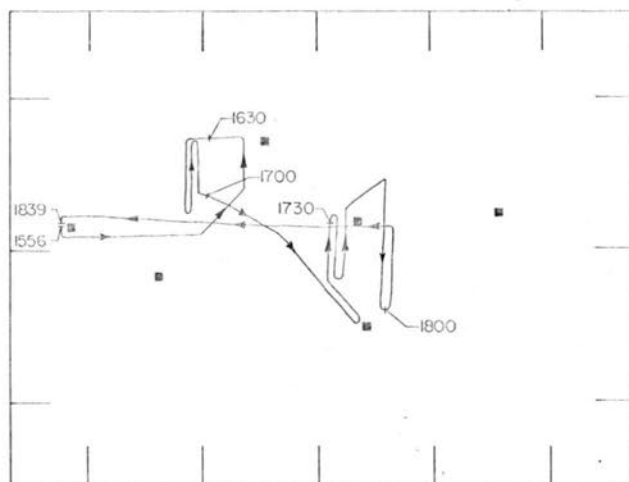
P. Location Identifiers.

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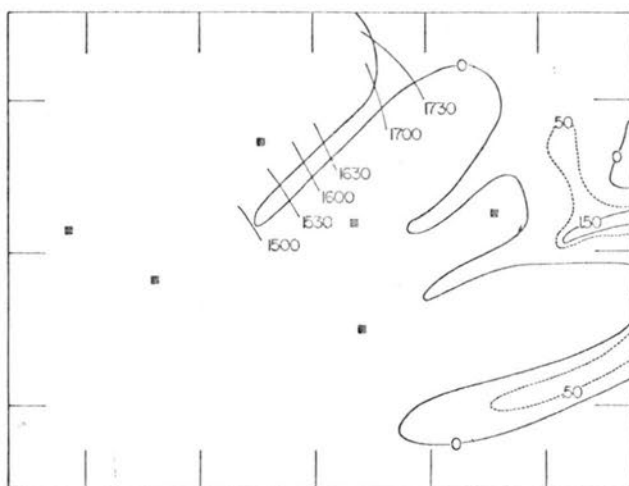
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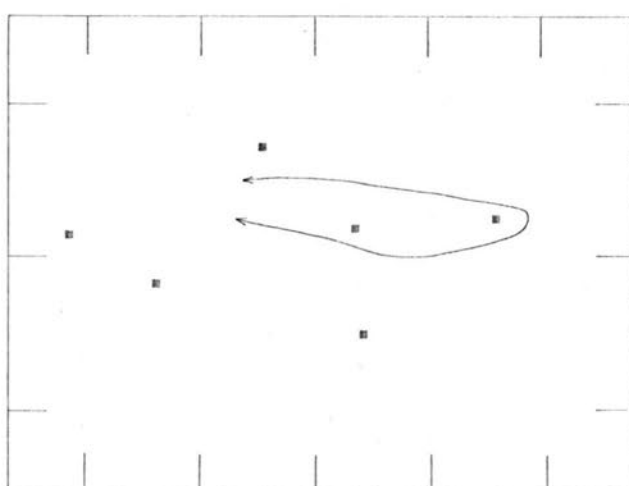
K. Track of Seeding Airplane.



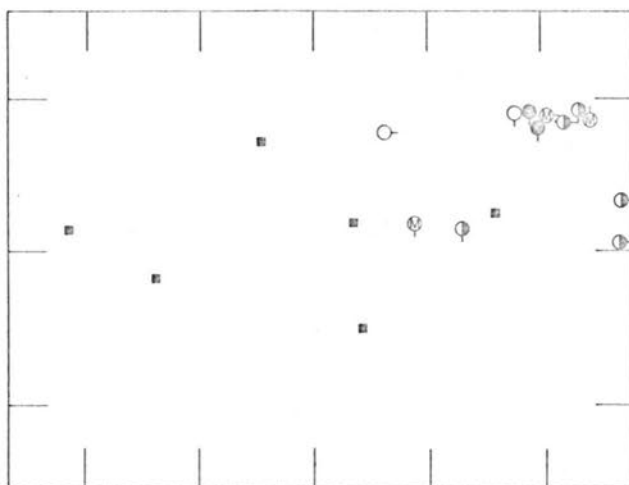
L. Track of Observation Airplane.



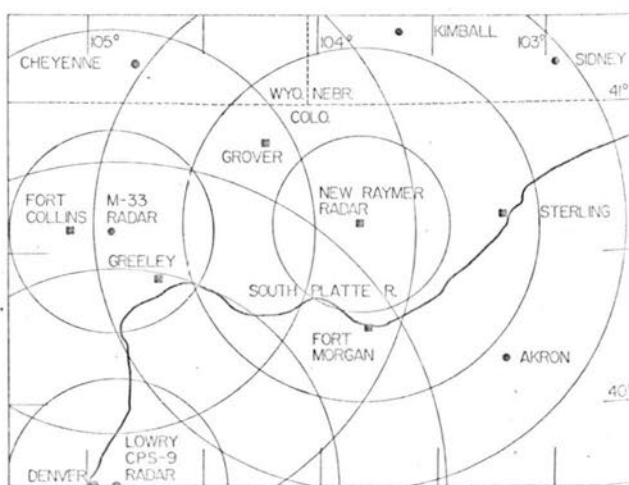
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



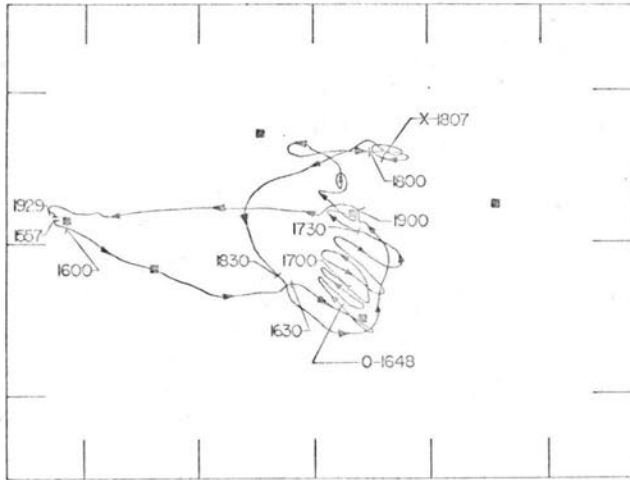
O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



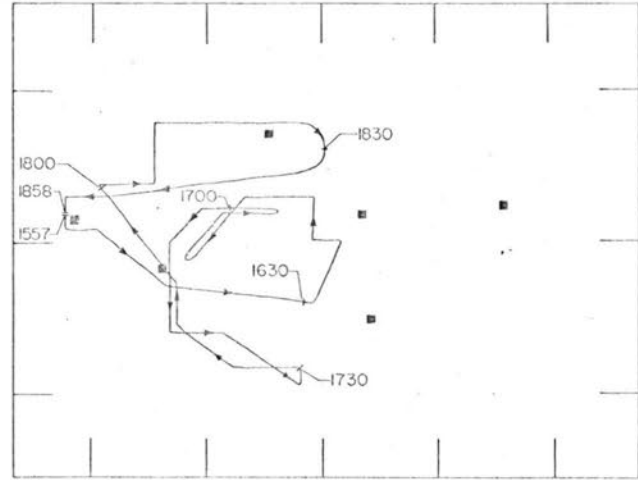
P. Location Identifiers.

7 July 1964

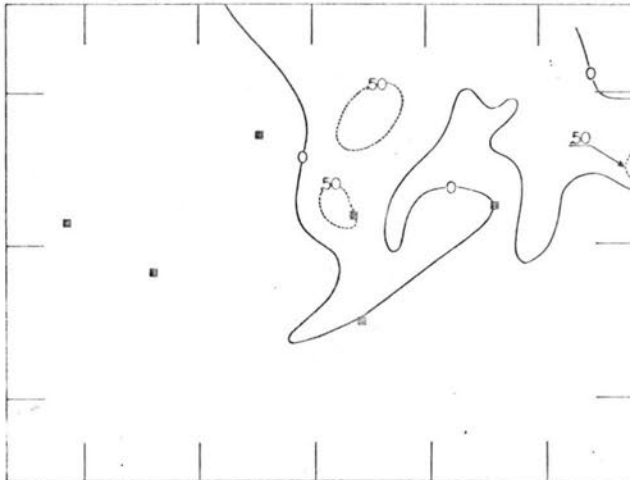
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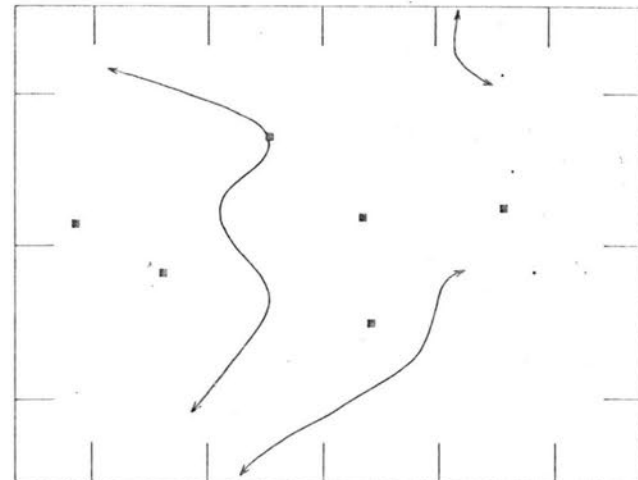
K. Track of Seeding Airplane.



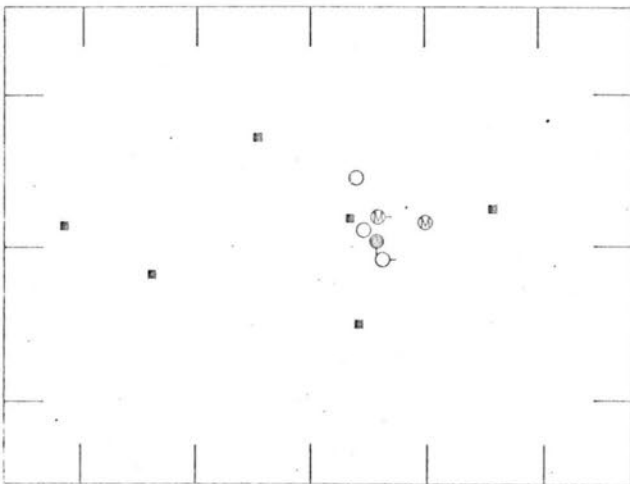
L. Track of Observation Airplane.



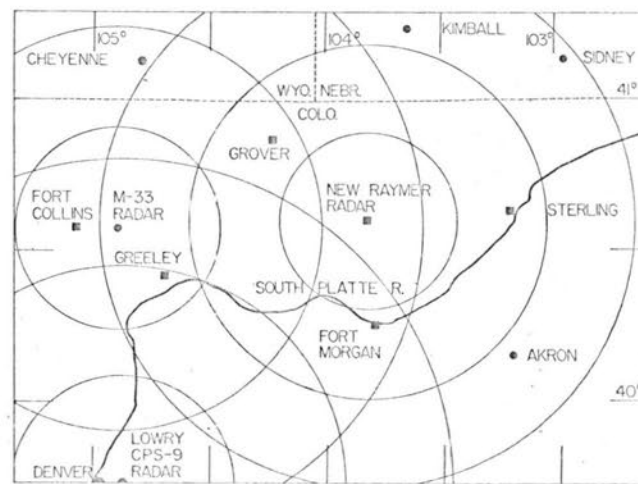
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



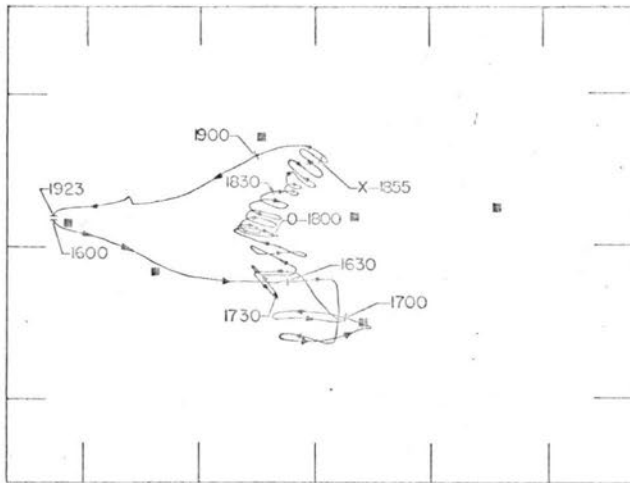
O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



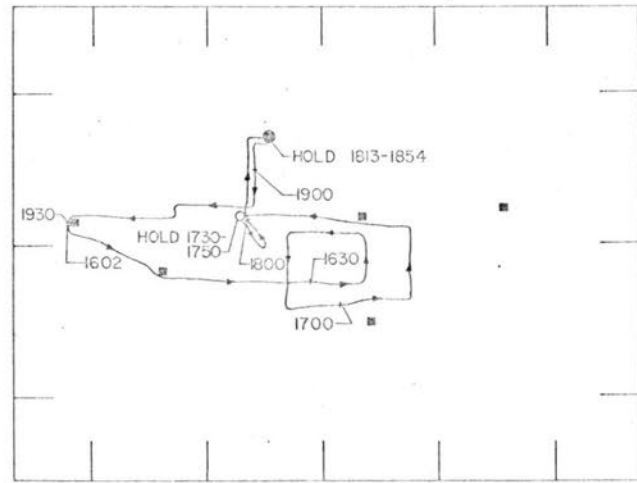
P. Location Identifiers.

8 July 1964

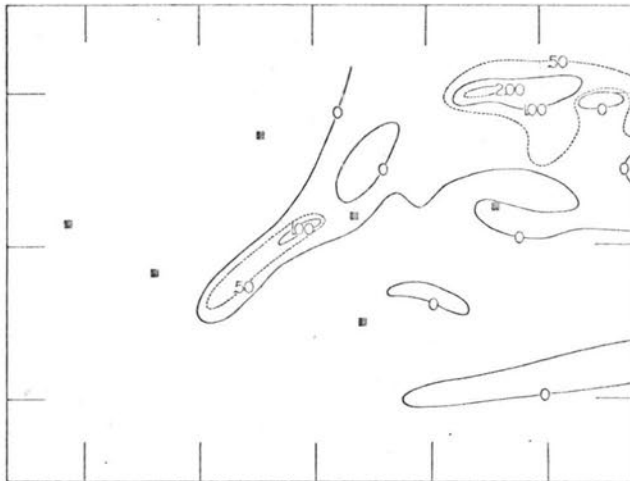
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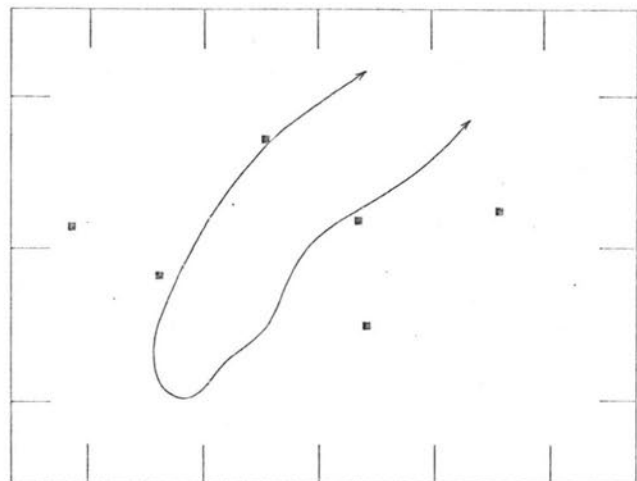
K. Track of Seeding Airplane.



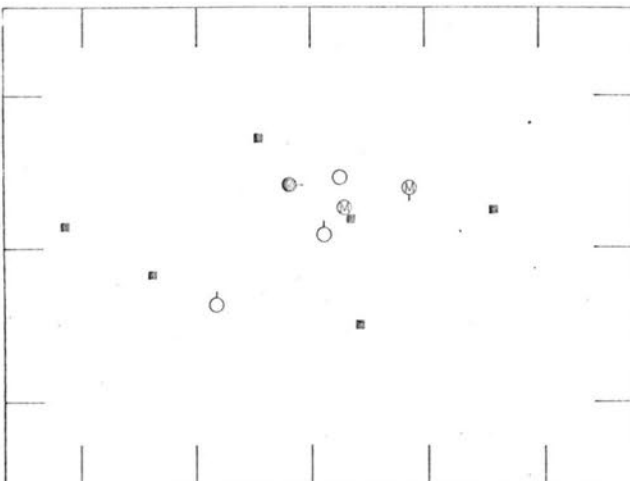
L. Track of Observation Airplane.



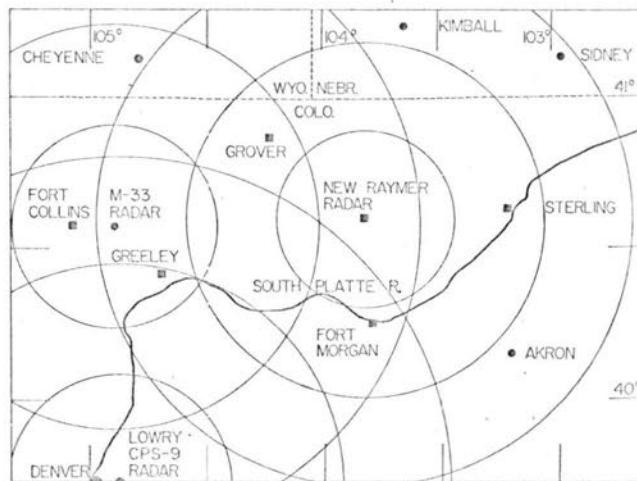
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



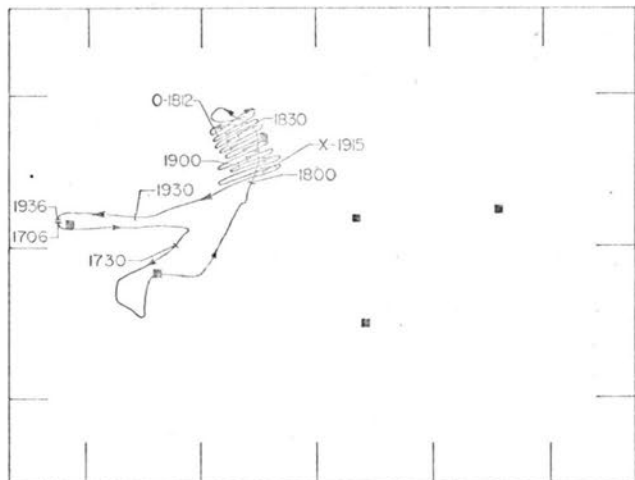
O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



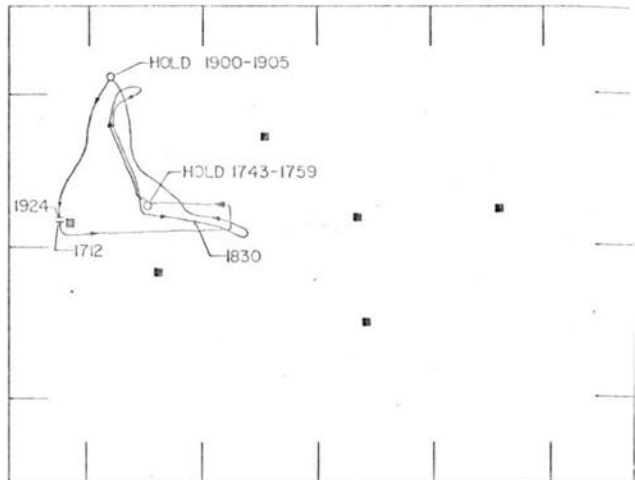
P. Location Identifiers.

9 July 1964

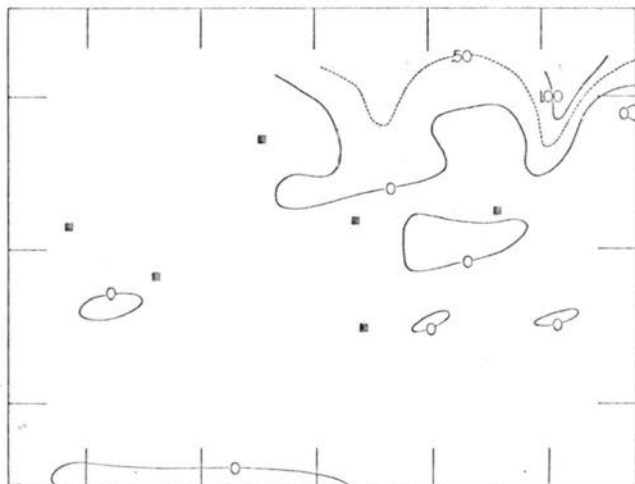
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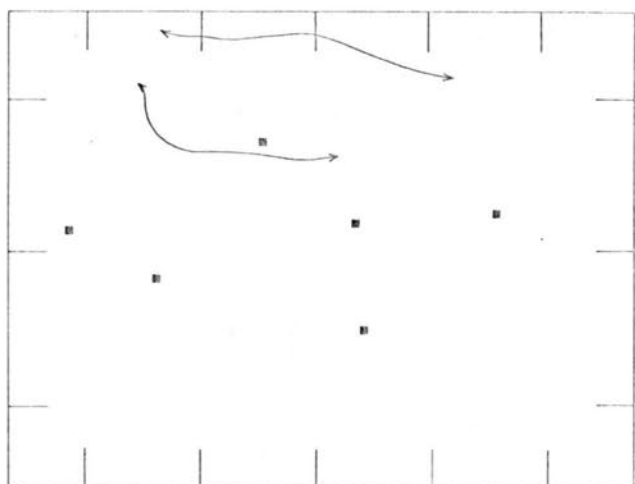
K. Track of Seeding Airplane.



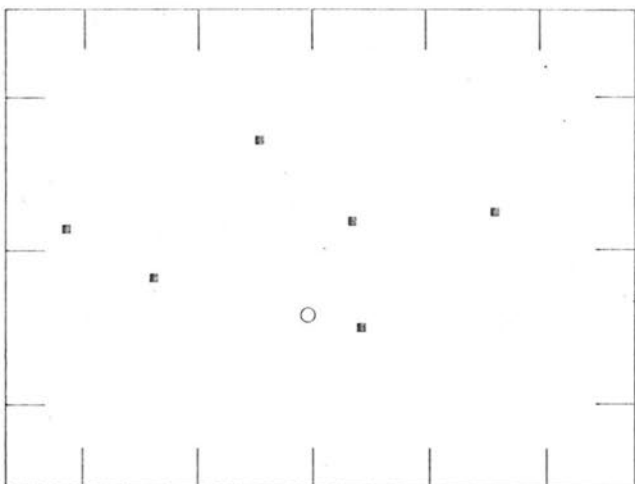
L. Track of Observation Airplane.



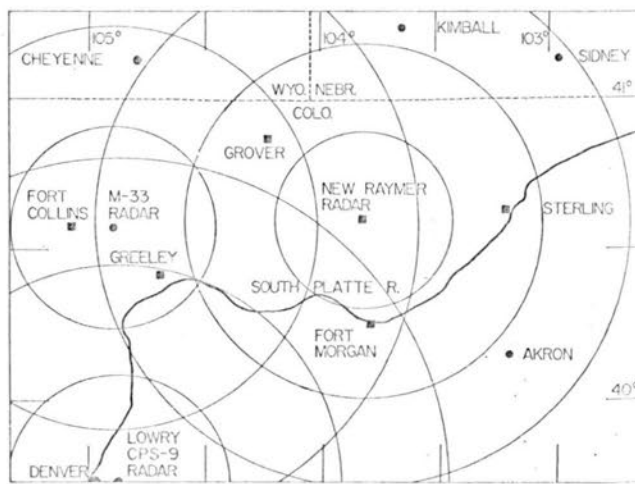
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.

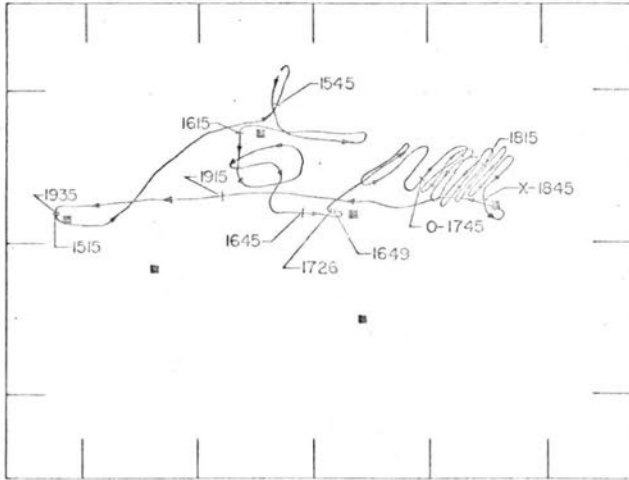


O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.

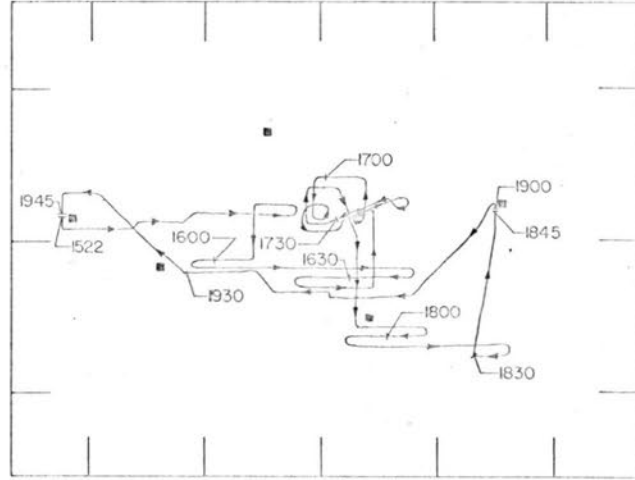


P. Location Identifiers.

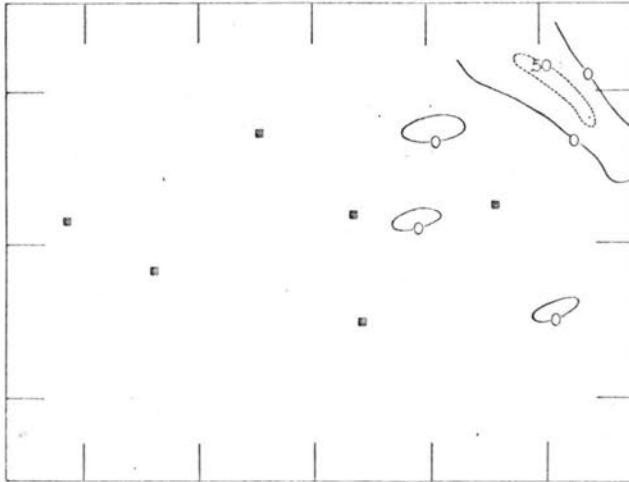
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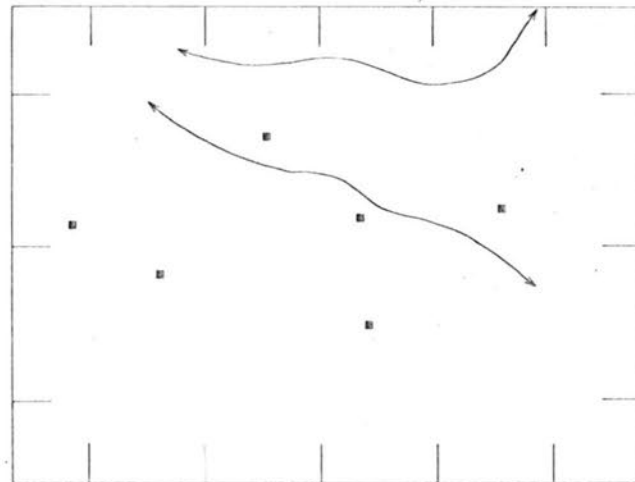
K. Track of Seeding Airplane.



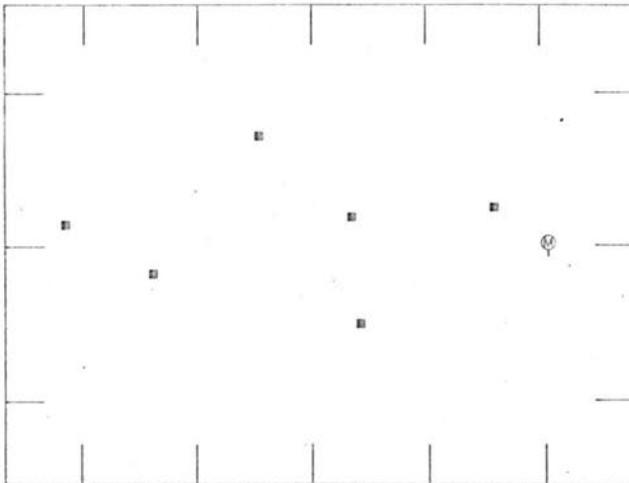
L. Track of Observation Airplane.



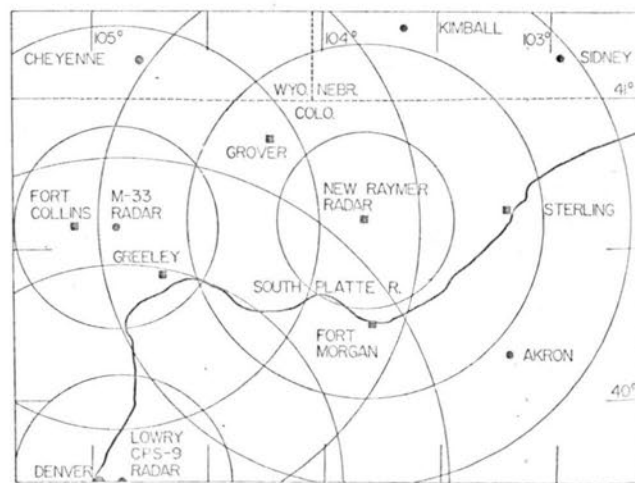
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



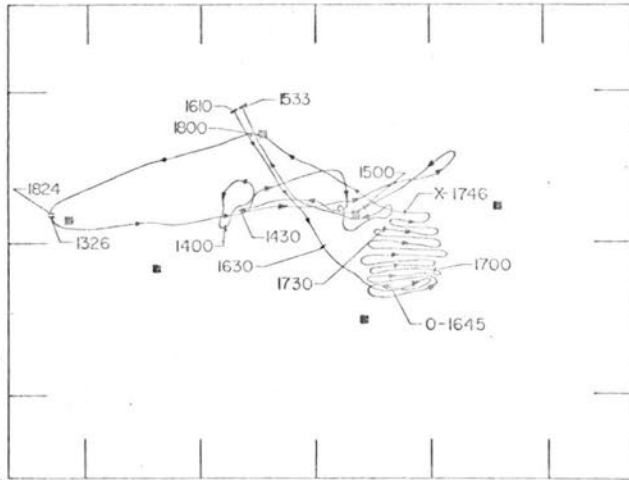
O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



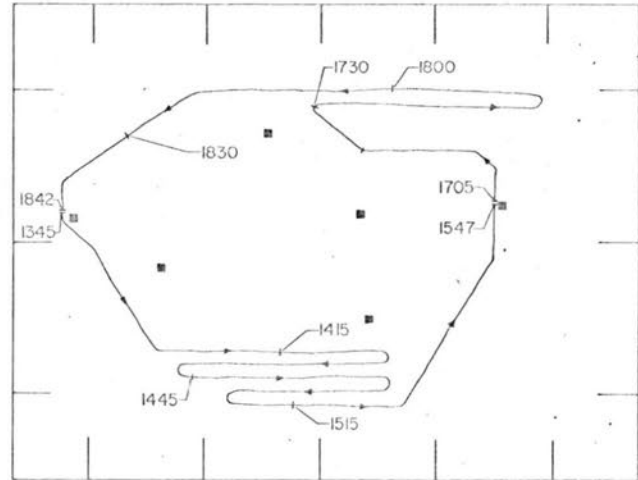
P. Location Identifiers.

30 July 1964

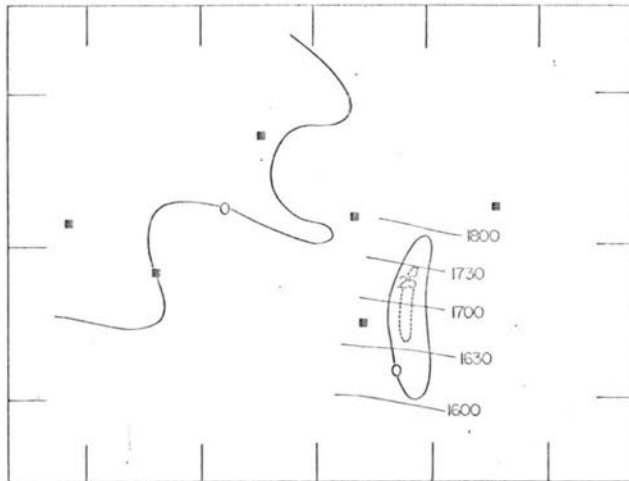
Figures K - P



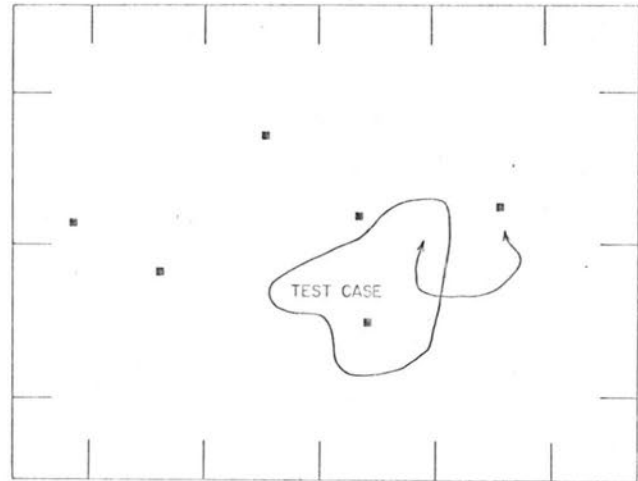
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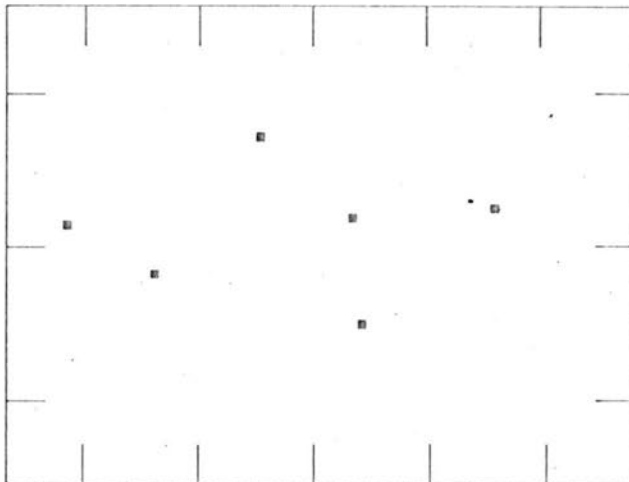
L. Track of Observation Airplane.



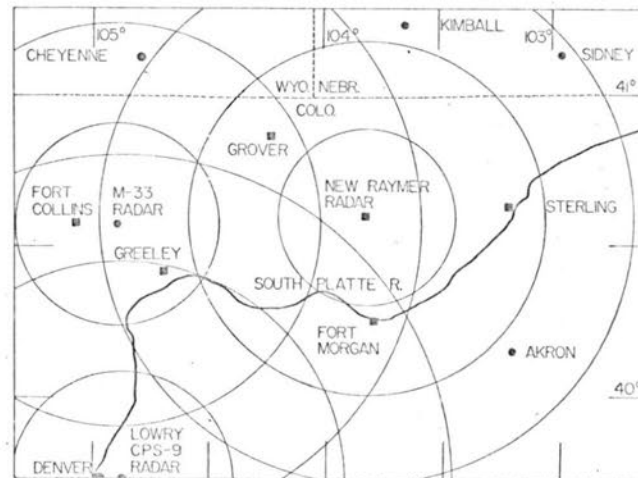
M. 24-Hour Rainfall Amount for a Period Ending 2400 MST.



N. Estimated Limits of Rain and Hail from Test Case.



O. Hailfall Reports for a 24-Hour Period Ending 2400 MST.



P. Location Identifiers.

