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RESEARCH PAPER NO. 33

Artificial Production of Precipitation

Third Partial Report: Orographic Stratiform Clouds--California, 1949.

Fourth Partial Report: Cumuliform Clouds--Gulf States, 1949.

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By

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The First Partial Report and Second Partial Report on the Artificial Production of Precipitation appeared as Research Papers No. 30 and No. 31, respectively. Any future Research Papers on this subject matter will be issued under the title Artificial Production of Precipitation.

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THIRD PARTIAL REPORT: OROGRAPHIC STRATIFORM CLOUDS - CALIFORNIA, 1949

INTRODUCTION

During 1948, the Cloud Physics Project conducted 40 cloud seeding experiments in stratiform clouds in the vicinity of Wilmington, Ohio. The results of these Ohio experiments have already been reported, [1, 2]. In order to secure a large and representative sample, these tests were all conducted in one particular locale. The findings were not necessarily of universal application, and it was recognized that areas having more favorable cloud conditions for seeding experiments might be found. Therefore, the decision was made to conduct a number of tests where it was believed that thick supercooled stratiform clouds would be formed systematically by the lifting of moist maritime air over a high mountain barrier. The particular area chosen for the tests reported here was in the vicinity of the Donner Pass of the Sierra Nevada Range, northeast of Sacramento, Calif. Seeding experiments were conducted there during the months of February, March and April, 1949. This phase of the Cloud Physics Project was a cooperative effort of the U. S. Air Force, U. S. Navy and U. S. Weather Bureau.

Experience gained in the Ohio tests indicated that at least two aircraft were necessary for the proper observation of results. Therefore, in the California tests, a B-17 seeding aircraft was used to fly above the seeded cloud and, whenever possible, a C-47 was used for observations from beneath the cloud deck. Because radar information had proved invaluable in properly evaluating the Ohio data, a high-powered 10 cm. search radar which was installed in a bomber aircraft was also used to monitor these tests. The general plan of attack was much the same as that previously described [1, 2].

It was hoped that during the period of these tests it would be possible to seed a number of supercooled, orographically-initiated stratiform clouds. However, this type cloud seldom occurred. Of the 9 days on which seeding operations were conducted, 6 had frontal clouds which even before seeding contained some natural ice crystals necessary for the formation of precipitation. On only 3 days during the period of these tests did the desired type of orographic cloud exist. This would seem to indicate that even as favorable an area as the one selected has suitable cloud conditions for seeding on only relatively few occasions. This statement is further borne out by the fact that in addition to the seeding flights, 10 reconnaissance flights made in the area during the same period indicated that natural clouds with ice crystals existed to over 25,000 feet as a result of frontal activity.

SUMMARY OF RESULTS

Table 1 briefly summarizes the data and results obtained. Of the 15 seedings, 7 resulted in the partial dissipation of the seeded deck. Holes as a result of seeding occurred in boundary area between the ice and water droplet regions. However, in each of these cases there was positive and definite natural dissipation occurring simultaneously in the immediate vicinity. The table also indicates the correlation between the divergence field as calculated by Bellamy's method [3] and the opening of holes in the cloud deck by cloud seeding. This table quite clearly shows that seeding was capable of dissipating sections of cloud when natural conditions were favorable; i.e. horizontal divergence existed. As a matter of fact, it was particularly difficult on the non-frontal days to find widespread areas of orographic decks without large natural breaks. Of the 8 cases in which no dissipation results were observed, 5 were associated with frontal systems and it is possible that the chaotic condition of the sky and the pre-existence of ice crystals accounted for the absence of positive observations. In addition to the continuous seedings, 4 single pellet seeding drops were made under favorable conditions. No results of large enough scale to be observed were indicated from any of these.

Precipitation amounts are not included in Table 1 since if any fell as a result of seeding, it was not detected. The orographic clouds seeded were thin and often broken in nature. Seeding could have caused only traces of precipitation from them.

Complete descriptions of each of the seedings and atmospheric soundings for each day of operation conclude this report.

Table 1.--Summary of data and results of 15 operations for seeding orographic clouds, California, 1949

Date	Frontal or Nonfrontal	Convergence (C) Divergence (D) Neutral (N)	Height of Top (ft.)	Temperature of Top (°C.)	Height of Base (ft.)	Temperature of Base (°C.)	Pounds CO_2 per mile	Clouds Supercooled	Dissipation Results	Comments
1949 Feb.15	F	D	10,650	-7.0	9,800	-6.0	3	Yes	Boundary area opened	Natural holes nearby
22	F	C	13,000	-8.0	9,000	-1.0	3	Yes	Possibly slight building	Chaotic sky interfered with observations
24	F	C	10,000	-7.0	8,500	-5.0	3	Yes?	None	Chaotic sky interfered with observations
24	F	C	10,000	-7.0	8,500	-5.0	3	Yes?	None	Chaotic sky interfered with observations
Mar. 1	F	D	13,100	-11.0	12,600	-12.0	[1]3	Yes	Boundary area opened	Natural holes nearby
2	F	D	18,500	-27.0	10,600	-10.0	[1]3	Yes[3]	Change in texture	Also built up about 500 ft.
9	F	C	12,200	-10.0	2,250	+8.0	3	Yes[3]	Narrow seeding line observations for short period only	
23	NF	N	9,600	-11.0	4,000	-2.0	[1]3	Yes	None	
23	NF	N	8,450	-8.0	4,000	-2.0	2	Yes	Holes opened	Natural dissipation adjacent
23	NF	N	7,800	-5.0	4,000	-2.0	1	Yes	None	
24	NF	D	12,800	-15.0	12,300	-14.0	[1]3	Yes	Boundary area opened	Natural hole along seeded path
24	NF	D	13,300	-15.0	12,300	-14.0	[1]3	Yes	Boundary area opened	Natural holes nearby
24	NF	D	15,900	-21.0	12,300	-14.0	[2]10	Yes	Boundary area opened	Natural holes nearby
Apr. 7	NF	N	14,000	-10.0	13,500	-8.0	3	Yes	Boundary area opened	Natural dissipation nearby
7	NF	N	14,000	-10.0	13,700	-8.0	Number of single pellets	No?	None	

[1] Single pellet drop also with no results observed.

[2] Instantaneous drop.

[3] Also ice crystals.

DESCRIPTION OF INDIVIDUAL SEEDING MISSIONS

Cloud Seeding Mission of February 15, 1949

Synoptic Situation--At 1000 PST, a dissipating upper cold front was located across central Nevada, thence through California to the vicinity of San Francisco. A band of precipitation was located north of the front in northern Nevada and California. Twelve hours later the front had dissipated with stations in western Nevada and central California reporting clear skies or scattered cirrus clouds; therefore the influence of the frontal system in creating or maintaining clouds was becoming less and less throughout the time of the mission.

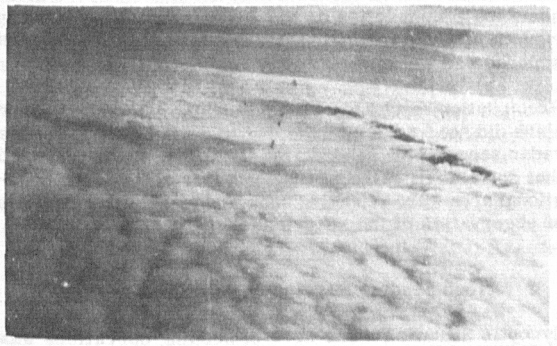


Figure 1.--Seeded area showing "L-shaped" pattern, February 15, 1949

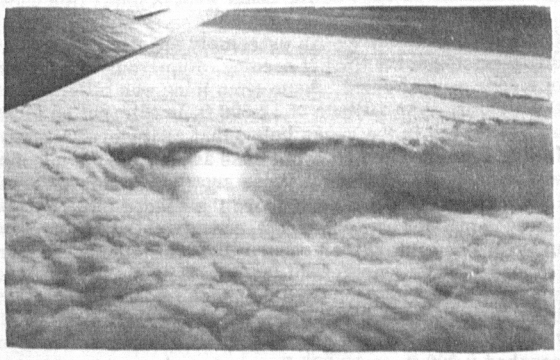


Figure 2.--Seeded area showing ice crystal structure, February 15, 1949. Note the sun pillars across the legs of the 'L'.

Conditions of Seeding--An altocumulus deck extending from 9,800 ft. to 10,650 ft. m.s.l., was seeded once in the shape of an 'L' (see fig. 1). The seeding was performed in a supercooled deck at a point 58° true heading and 28 statute miles from McClellan Air Force Base - a position immediately southeast of Auburn, Calif. The initial seeding was above 1,000-ft. terrain and as the seeded area progressed southward it did not pass over higher terrain until it reached the vicinity of Fiddletown. At that point the terrain rose another 1,000 ft. The temperatures in the vicinity of the cloud deck ranged from -6.0° C. at the base to -7.0° C. at the top. Glories were observed on the undisturbed portions of the cloud deck while sun-pillars were observed in the seeded area. Icing conditions were noted when the plane was flown through the clouds.

Rate of Seeding--Dry ice pellets were dropped at the rate of 3 pounds per mile

Time and Duration of Seeding:

1st Seeding:
1st leg: 1535:55 PST; 1 minute plus 30 seconds.
2nd leg: 1737:50 PST; 1 minute plus 40 seconds.

Results--First reconnaissance of the seeded area revealed a slight ridge development along the seeded path. Approximately 22 minutes after the initial starting time, the first lowering of the top of the seeded cloud was observed. At the same time the area had spread horizontally to a maximum size of 1-1/2-miles. By 1645 PST, after several fluctuations in the cloud elements of the seeded area, a definite hole 3 to 4 miles across was observed at the apex of the 'L'. Previous to that time, however, flights directly over the seeded area revealed intermittent spots through which the observers could see the ground.

No precipitation was observed by the radar controller; therefore it was believed that no rain resulted from the seeding.

Method of Verification:

Structural:
1st Seeding: Aerial observations (visual) and photographs (figs. 1 and 2) of the seeded and unseeded portions of the cloud.

Precipitation:
1st Seeding: Radar observations by the controller. Visual observations of the base of the clouds in the vicinity of the seeded area after completion of the mission indicated no precipitation within the vicinity of the seeded portion of the clouds.

Comments--The results of this mission may have been the most decisive of any mission to date; but on the other hand, after a closer check was made, some doubt arose as to whether the results were as spectacular as they first appeared to be. At the time of the seeding run the deck was apparently solid in all directions from the seeding points; but at the completion of the mission, portions of the deck outside of the seeded area were thin enough for observations of the ground beneath to be made. It was noted that the air flow was from northwest to southeast which resulted in the seeded area moving toward an area of less and less cloud cover. The fact that the upper cold front was dissipating also indicated the possibility that initially overcast skies were destined for dissipation through natural causes. Observations made from the air and on the ground lent confusion as to whether the dissipation of the front was causing general widespread reduction in cloud cover during the seeding operations; but the air observers concluded that natural dissipation and fluctuations of the cloud cover were occurring locally throughout the entire mission.

A VFR letdown was made at the apex of the 'L' (the only area in the seeded pattern that was completely clear of clouds) approximately 1-1/2 hours after the initial seeding; but at the same time, points outside the seeded area were noted where the identical procedure could have been followed. Such points were to the north of the seeded portion thereby removing any possibility of such areas having been

affected by the seeding.

Several runs were made for the sole purpose of measuring and comparing the tops of the cloud elements that remained in the seeded area with those of the unseeded cloud. It was then noted that the tops of the clouds in the seeded area were only 100 ft. lower than those of the surrounding clouds.

Since the clouds were moving roughly along the valley on the west slope of the mountain range, it is doubtful that the topography had any pronounced effect on the formation or dissipation of the cloud deck or the seeded area. Clouds of similar height and type were observed further to the west; therefore the seeded cloud deck probably originated under the influence of the southward moving upper cold front. Assuming that such was the case, it is logical that such clouds would have a tendency to dissipate after the frontal influence was no longer present.

A low observation plane did not fly the mission, but since there was no echo observed on the radar scope by the controller, it was assumed that no rain fell from the seeded area or from clouds within 30 miles thereof. Intermittent snow showers were occurring, however, within 35 to 50 miles of the area where the initial drop was made.

Cloud Seeding Mission of February 22, 1949

Synoptic Situation--The area of seeding operations was located in a pre-cold frontal position. A cold front located across northwestern California at 1030 PST moved across the operational area during the succeeding twelve hours. Scattered rain showers were occurring ahead of the frontal system.

Conditions of Seeding--The sky was very chaotic in appearance with numerous layers of thin clouds plus a few cumulus tops protruding through them. Because of the confusion of cloud decks, observations of seeding results were very difficult. The lack of sunshine prohibited the possibility of observing or photographing satisfactorily any color contrasts that may have resulted from the seeding. After much delay, an area of altocumulus clouds was picked for seeding. The deck was supercooled and lay between 9,000 ft. and 13,000 ft. m.s.l. The seeding run at 12,200 ft. m.s.l. resulted in the aircraft passing in and out of the irregular tops of the clouds. Temperatures ranged from -1.0° C. at the base to -8.0° at the top.

Rate of Seeding--Dry ice was dropped on a straight line run at the rate of 3 pounds per mile.

Time and Duration of Seeding:

1st Seeding: 1014:30 PST; 2 minutes plus zero seconds.

Results--Negative dissipation results were observed, however, the confused cloud conditions that existed prevented accuracy of the observations as far as texture change was concerned. Some building of the cloud was observed, but slight building of the bulges on top of the cloud deck was noted prior to the seeding run.

Precipitation results were not definitely determined; but the observers, making visual observations, did not believe that any rain fell from the seeded area.

Method of Verification:

Structural:
1st Seeding: Aerial observations (visual) and photographs of the seeded area.

Precipitation:
1st Seeding: Visual observations of the seeded area. Ground observations indicated that precipitation was falling within 30 miles of the seeded area.

Comments--This mission was carried out under extremely adverse conditions. Multi-layer clouds created confusion and indefiniteness of seeding result observations. In addition, mechanical failure of the aircraft necessitated the abandonment of the area after twenty minutes reconnaissance. It was noted, however, that building was evident after seeding, but this result lacks significance - the building was also observed prior to the seeding run. One observer reported a faint glory on the cloud deck in the vicinity of the seeded area and still another observer noted some ice accumulation on the aircraft during the seeding run - a possible indication that the deck was composed of supercooled water.

Precipitation results were also doubtful. A low observation plane did not fly the mission, but no echo was noted on the radar scope in the seeded area; therefore it was assumed that no rain fell. Ground stations very close to the operational area were reporting snow and sleet during the time of observation of the seeded area.

Cloud Seeding Mission of February 24, 1949

Synoptic Situation--The area of seeding operations was located to the west of an upper cold front oriented at 1030 PST in a north-south direction through central Nevada and southeastern California. A frontless low pressure area was centered off the Pacific Coast west of San Francisco.

Conditions of Seeding--An extremely chaotic cloud condition existed at the time of seeding. Numerous thin layers of clouds were present. Some rime icing was observed on the aircraft at an altitude of 12,500 ft. m.s.l., but no icing was observed in the decks below that altitude. Rain was falling at McClellan Air Force Base at the time the mission was organized. At various times snow was observed to be falling from the cloud deck above the seeded one. By the time the mission was completed, considerable improvement in weather conditions had occurred at McClellan - the rain had ended and dissipation of the clouds over the base was conspicuous. The deck finally chosen for seeding had its base ranging from 8,000 ft. m.s.l. to 8,500 ft. m.s.l. with temperatures ranging from -4.0° to -5.0° C. The tops reached 9,200 ft. to 10,000 ft. m.s.l. and considerable irregularity in their heights was noted on both seeding runs. Temperatures near the tops ranged from -5.0° to -7.0° C.

Rate of Seeding--Dry ice was dropped at the rate of 3 pounds per mile on both seeding runs.

Time and Duration of Seeding:

1st Seeding: 1057:50 PST; 0 minutes plus 55 seconds.
2nd Seeding: 1121:50 PST; 2 minutes plus 25 seconds.

Results--Dissipation results were negative after both seeding attempts. A low observation plane did not fly the mission, but since no radar echo was observed it was assumed that no precipitation fell. (It should be mentioned, however, that ground interference on the radar scope made possible precipitation echoes very hard to distinguish.) Visual observations through natural openings of the cloud deck also indicated that no rain fell as a result of the seeding.

Method of Verification:

Structural:
1st and 2nd Seedings: Visual observations (aerial) and photographs of the seeded area.

Precipitation:
1st and 2nd Seedings: Visual observations and pictures of radar scope. (Scope pictures were not on Video throughout the entire mission.)

Comments--The first seeding was performed over the airways east of Auburn Airport, Calif., and the second seeding was in the vicinity of Marysville, Calif. Although natural holes were observed very close to the seeded areas, none appeared as the result of seeding. There is some doubt, however, as to whether the seeded clouds were supercooled. After the mission, runs were made into the altocumulus deck and no icing was observed at that time. Even though the temperatures of the air in the vicinity of the seeded areas indicated the clouds to be supercooled, the lapse rates in the clouds may have been sufficiently removed from that of the surroundings that the cloud would have had above freezing temperatures. Occasionally, when the sun's rays shone through the upper deck on to the seeded one, glories were observed on top of the seeded cloud - an indication that the cloud was composed of water droplets. Precipitation was observed within 30 miles of the seeded area.

Cloud Seeding Mission of March 1, 1949

Synoptic Situation--At 1030 PST a surface cold front was located off the northern California Coast. The front was apparently very slow moving because twelve hours later it was still off shore. A very weak low pressure wave developed on the front northwest of San Francisco during the twelve hours following the mission. Areas of occasional rain were occurring ahead of the frontal system in northern California. During the succeeding twelve hours, the precipitation areas remained practically unchanged with very little eastward movement.

Conditions of Seeding--The sky condition was very much the same as it had been on several previous missions - characterized by chaotic conditions resulting from numerous thin cloud layers of varying amounts. The deck finally earmarked for seeding was an altocumulus deck extending from 12,600 ft. m.s.l. to 13,100 ft. m.s.l. Temperatures ranged from -11.0° to -12.0° C. The 'L' shaped seeding pattern was started at a point 42 miles from McClellan Air Force Base on a true heading of 070°. In addition to the 'L' pattern, one ice pellet was dropped at the diagonal point from the apex of the 'L'.

Rate of Seeding--Dry ice pellets were dropped at the rate of 3 pounds per mile.

Time and Duration of Seeding:

1st Seeding:
1st leg: 360° heading; 0954:57 PST; 1 minute plus 28 seconds.
2nd leg: 090° heading; 0956:55 PST; 1 minute plus 30 seconds.
Single pellet: 1000:25 PST.
(All seeding headings are compass headings)

Results--The first apparent result was a slight rise in the seeded area. Approximately 30 minutes after seeding, a hole was noted in the seeded area; but natural holes were observed very close by. No results were observed in the area where the single pellet was dropped.

Visual observations by the observers in the seeding aircraft indicated that no precipitation fell from the seeded portion of the cloud.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial) and photographs of seeded and unseeded portions of the cloud. (Presence of upper cloud deck reduced the quality of the photographs.)

Precipitation:
1st Seeding: Visual observations (aerial).

Comments--Even though holes did appear in the seeded area, the changes observed were in phase with those occurring naturally within visual range of the observers. It was noted that the clouds became gradually thinner through natural causes as they approached the Lake Tahoe area. The first appearance of the holes in the seeded area was observed only after the seeded area had moved to a position within 10-20 miles of Lake Tahoe. Concurrently, natural holes were observed to form in the same area - some of them to the west of the seeded area which precluded the possibility of the seeding having an effect upon the area - the clouds were moving from southwest to northeast.

The observers were finally forced to abandon the area; so many natural holes formed in the deck that it became virtually impossible to follow the seeded portion. The natural holes as well as the seeded ones began to form in the cloud deck as the areas approached the crest of the mountain range. In this area such changes were local in character, however, 10-15 miles north of the seeded position the clouds continued overcast in the Blue Canyon and Donner Pass area with occasional snow showers.

A low observation plane did not fly the mission but observers in the seeding aircraft were reasonably sure that no precipitation fell as a result of seeding. Observations of this kind were made occasionally through the natural openings in the cloud deck as well as through the openings in the seeded area.

Cloud Seeding Mission of March 2, 1949

Synoptic Situation--The seeding operations were performed in a cold frontal zone running north-south through central California. The front was a slow moving surface cold front at the time of the mission, but during the subsequent twelve hours it moved aloft. Areas of precipitation were present ahead of the frontal system throughout the state of California and several heavy rain showers occurred at McClellan Air Force Base during the mission operations.

Conditions of Seeding--The characteristic confused cloud conditions existed on this mission as on previous ones. The altocumulus cloud deck chosen for seeding was based at 10,600 ft. m.s.l. with average tops near 18,500 ft. m.s.l. The temperatures ranged from -10.0° to -27.0° C. The deck was composed of both ice crystals and supercooled water. Occasional snow was encountered from 4,900 ft. m.s.l. to 18,500 ft. m.s.l. Another cloud deck was present above the seeded one, but occasional sunshine on the top of the seeded deck made possible the observation of sunspots before the seeding was begun. Light rime icing was encountered in the cloud deck also. The seeding was in an

'L' shaped pattern with a single ice pellet being dropped on a diagonal point from the apex of the 'L'.

Rate of Seeding--Dry ice pellets were dropped at the rate of 3 pounds per mile.

Time and Duration of Seeding:

1st Seeding:
1st leg: 360° heading; 1119:05 PST; 1 minute plus 30 seconds.
2nd leg: 090° heading; 1121:20 PST; 1 minute plus 17 seconds.
Single pellet: 1135:05 PST.
(All seeding headings are compass headings)

Results--The seeded area immediately changed texture and apparently rose about 500 ft. No further reaction was observed except that the ridge became diffuse and was finally lost after 20 minutes reconnaisance. No results were observed from the single pellet drop.

Accurate observations of precipitation results were not made, but since it was raining or snowing generally over the area, it was assumed that precipitation was falling from the cloud both before and after seeding.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial) and photographs of seeded and unseeded portions of the clouds. (Photographs were poor in quality because of light deficiency.)

Precipitation:
1st Seeding: Visual observations (aerial) and ground observations in the vicinity of the seeded area.

Comments--The seeding was performed in the vicinity of Grass Valley, Calif. The movement of the seeded area thereafter was from the south-southwest to the north-northeast. The cloud deck had very irregular tops which made observations difficult. The sky condition presented a very confused picture with fluctuations of considerable magnitude evident throughout the mission. Occasionally, holes were observed in the cloud deck; some of them were so large that the ground could be seen 50-60 miles away from the observation point.

The cloud, as evidenced by the accumulation of rime ice on the aircraft and the occasional appearance of sunspots on top of the clouds, contained ice crystals. On the other hand, some texture change was observed after seeding; therefore some supercooled water must have been present also. The deficiency of supercooled water may have been responsible for the lack of more significant results.

It could not be definitely determined whether or not precipitation resulted from the seeding, but since rain was general over the area, it was assumed that precipitation must have been falling both before and after seeding.

Cloud Seeding Mission of March 9, 1949

Synoptic Situation--A cold front was immediately off the Pacific Coast at 1030 PST, and during the next 12 hours it moved to western Nevada-central California and changed from a surface front to an upper cold front. A large band of precipitation was associated with the frontal system.

Conditions of Seeding--An altocumulus cloud deck was seeded once. The top of the deck was near 12,200 ft. m.s.l. Numerous cloud layers existed below the seeded deck with the initial layer based at 2,250 ft. m.s.l. The decks were so intermingled that a definite measurement of the base of the seeded deck could not be obtained. Temperatures ranged from +8.0° C. at 2,250 ft. m.s.l. to -10.0° C. at the top of the seeded deck. Observers reported snow showers and a noticeable accumulation of rime ice on the aircraft as they ascended to 13,000 ft. m.s.l. While circling the seeded area, the observers noted sunspots on the top of the cloud deck several times. No turbulence was encountered in the cloud layers.

Rate of Seeding--Dry ice pellets were dispensed at the rate of 3 pounds per mile.

Time and Duration of Seeding:

1st Seeding: 1535:25 PST; 1 minute plus 30 seconds.

Results--Immediately after seeding, it was believed that a white line appeared along the seeded path, but the observations were very indefinite and unreliable. It was finally agreed that the seeded portion of the cloud was no different than other undisturbed portions within the immediate vicinity.

Light precipitation was falling from the clouds both before and after seeding.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial) of the seeded area and photographs of the area indicating no results.

Precipitation:
1st Seeding: Visual observations (aerial) and synoptic weather reports in the vicinity of the seeded area.

Comments--The seeding was performed along the northeastern edge of Clear Lake, Calif., and the seeded area subsequently progressed in a north-northeast direction. The lack of significant results after seeding was probably not important since it was believed that the cloud deck was composed of ice crystals prior to the seeding operations. The observations of snow, rime icing, and sunspots verified the assumption.

Showers were general over the area throughout the entire mission. McClellan Air Force Base reported a heavy shower during the time the mission was in progress, and synoptic reports very close to the seeded area indicated that continuous light rain was falling. Since natural showers were occurring at the time of seeding, any rain falling from the seeded portion of the cloud would lack significance.

Cloud Seeding Mission of March 23, 1949

Synoptic Situation--The seeding was performed in a fresh maritime polar airmass that had moved into the area following the passage of a cold frontal system 30 to 36 hours previously. The low pressure system and associated frontal system were a considerable distance east of the operational area at the time of seeding.

Conditions of Seeding--A stratocumulus cloud deck with occasional cumulus buildups protruding through it was seeded three times. The tops varied from 9,600 ft. m.s.l. on the first run to 7,800 ft. m.s.l. on the last run. The top of the deck sloped upward along the mountain slope to 11,400 ft. m.s.l. near the summit. Temperatures near the top of the seeded portions were -11.0°, -8.0°, -5.0° C.

respectively on the seeding runs. The base of the clouds were near 4,000 ft. m.s.l. with a temperature of -2.0° C. Occasional buildups of cumulus clouds were especially prevalent near the second seeding position. Fort Stockton was reporting heavy cumulus in all quadrants at the time of the first and the second seeding. Some clear icing was observed as the ascent was made through the cloud deck. Even though precipitation was not observed in the seeded areas, rain was reported within 30 miles of the first seeded area and within 50 miles of the second and third areas. The first seeding was in the shape of an 'L' while the last two were straight line runs. At the diagonal corner from the apex of the 'L', a single ice pellet was dropped.

Rate of Seeding--Dry ice pellets were released at the rate of 3, 2, and 1 pound per mile respectively on the three seeding runs.

Time and Duration of Seeding:

1st Seeding:
1st leg: Heading 270°; 1017:40 PST; 1 minute plus 40 seconds.
2nd leg: Heading 360°; 1020:00 PST; 1 minute plus 40 seconds.
Single pellet: 1026:55 PST.
(All headings are compass headings)
2nd Seeding: 1047:15 PST; 2 minutes plus 15 seconds.
3rd Seeding: 1131:05 PST; 1 minute plus 30 seconds.

Results--Nothing of significance was observed after the first and third seedings. There was no apparent result from the single pellet drop. After the second seeding, the seeded area dissipated so that the ground beneath could be observed through the opening. Some cloud particles, however, remained in the area.

No precipitation was observed in the seeded areas.

Method of Verification:

Structural:
1st and 3rd Seedings: Visual observations (aerial) and photographs indicating no results.
2nd Seeding: Visual observations (aerial) and photographs of seeded area. (See fig. 3)

Precipitation:
1st, 2nd and 3rd Seedings: Visual observations (aerial) and synoptic weather reports in the vicinity of the seeded area.

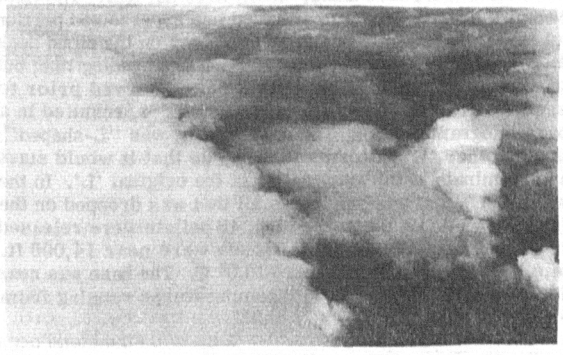


Figure 3.--Second seeded area approximately 33 minutes after seeding, March 23, 1949.

Comments--This was the only mission to date in which two aircraft were involved. The seeding plane was followed very closely by an observation plane with excellent coordination resulting in more accurate observations of the seeded areas. The observers in both aircraft reported no results after the first and third seedings, but all agreed to positive results after the second run. The lack of results after the first and third runs may have been significant, but the character of the cloud deck could have easily hindered complete observations of the reactions by obscuring all changes of a minor nature. Since the observers were fairly confident, however, that the clouds were supercooled (clear icing observed during ascent through the cloud deck and the observation of a glory in the vicinity of the third seeded area substantiate their confidence) it is significant that the seeding resulted in only 33 percent success in creating VFR conditions while natural breaks and similar conditions were observed in the vicinity of all seeded areas. Furthermore, the results of the second seeding did not appear to follow the usual chain of events as observed on previous seeding missions. A change in texture was not apparent, but the area seemed to open up very rapidly without noticeably going through the intermediate stages. Such rapid changes linked with observations of natural breaks close by may indicate that some natural dissipation was responsible for part of the results observed.

Cloud Seeding Mission of March 24, 1949

Synoptic Situation--The area of seeding operations was located on the eastern edge of the Pacific sub-tropical high pressure system and the resulting general circulation was from north to south.

Conditions of Seeding--Three seeding runs were made on a supercooled altocumulus cloud deck. The deck was very broken and in some spots it was so thin that the ground could be observed through the cloud elements. The area for seeding was chosen near the summit of the mountains in the vicinity of Donner Summit and Truckee, Calif. The first two seedings were in the shape of an 'L' while the last one was an instantaneous drop near the second seeded position. A single pellet was released at the diagonal point from the apex of the 'L's' after the first two runs. The tops of the clouds ranged from 12,800 ft. m.s.l. to 15,900 ft. m.s.l. with temperatures varying from -15.0° to -21.0° C. The base was not accurately determined, but the only measurement made indicated it to be near 12,300 ft. m.s.l. Since the cloud deck did not become appreciably thicker as the tops changed from the first to the third seeding, it was assumed that the bases rose also. Temperatures near 12,300 ft. m.s.l. were about -14.0° C. No icing was observed because the ascent was made under VFR conditions; however, glories were observed on the cloud deck thereby indicating supercooled water was present. The clouds were breaking up naturally throughout the entire mission. They were changing from a stratocumulus or altocumulus appearance to a broken cumulus or cumulonimbus. Several showers were occurring within 30-60 miles of all seeding areas.

Rate of Seeding--Dry ice pellets were dropped at the rate of 3 pounds per mile on the first run, 3 pounds per mile on the second run, and 10 pounds instantaneously on the third run.

Time and Duration of Seeding:

1st Seeding:
1st leg: Heading 200°; 1404:25 PST; 1 minute plus 38 seconds.
2nd leg: Heading 330°; 1407:10 PST; 0 minutes plus 45 seconds.
Single pellet: 1410:33 PST.

2nd Seeding:
1st leg: Heading 320°; 1446:15 PST; 1 minute plus 25 seconds.
2nd leg: Heading 020°; 1448:25 PST; 1 minute plus 30 seconds.
Single pellet: 1452:15 PST.
3rd Seeding: 1530:30 PST; instantaneous.
(All headings are compass headings)

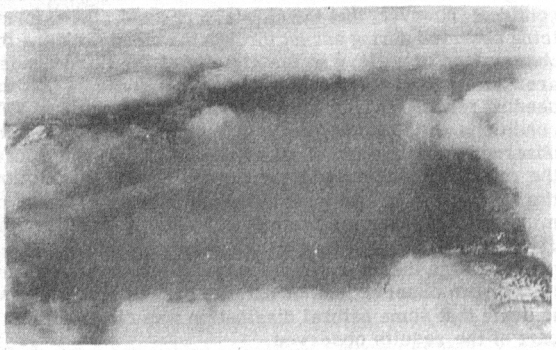


Figure 4.--First seeded area approximately 30 minutes after seeding, March 24, 1949.

Figure 5.--Second seeded area approximately 13 minutes after seeding, March 24, 1949.

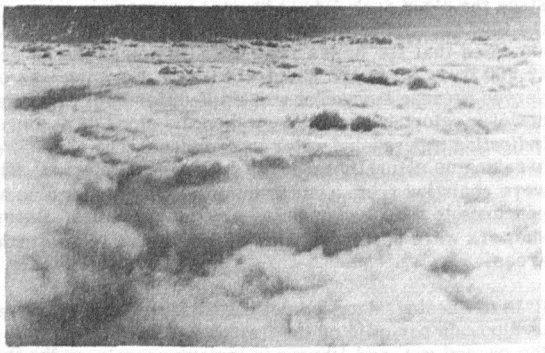


Figure 6.--Third seeded area approximately 22 minutes after seeding, March 24, 1949.

Results--Definite texture changes were observed after all seedings except in the areas where the single pellets were dropped. The single pellet dropped on the first seeding run, however, was released into an area that was void of cloud. The ice crystal portions that resulted after seeding separated from the water portions of the cloud and VFR conditions existed along the periphery of each seeded area. The ice crystal portions seemed to exist longer than the surrounding water cloud that was in the process of natural dissipation.

No precipitation was observed after any of the seeding runs.

Method of Verification:

Structural:
1st, 2nd and 3rd Seedings: Visual observations (aerial) and photographs of the seeded cloud (see figs. 4, 5 and 6).

Precipitation:
1st, 2nd and 3rd Seedings: Visual observations (aerial), radar scope pictures, and synoptic weather observations in the vicinity of the seeded areas.

Comments--It was significant that the ice crystal cloud separated from and existed longer than the dissipating portions of the water cloud. There were many natural breaks close to all seeding areas. In fact, the second leg of the first run was cut short because the seeding path extended into areas that were void of cloud. The single pellet drop on this seeding was also released into a clear spot. The characteristic rise after seeding that had been observed on previous missions failed to develop after any of the drops on this date. On the contrary, the texture change and slight lowering of the seeded portions were the results observed. It was noted that numerous cumulus clouds were developing in the immediate vicinity of all seeded areas with some of them reaching the cumulonimbus stage. Several natural showers were occurring over the mountains within 30-60 miles of the seeded areas, but no rain was observed in the seeded portions. This is not too surprising, however, since the cloud was never observed to be more than about 500 ft. thick - too thin for any significant precipitation to have been expected even from natural causes.

Cloud Seeding Mission of April 7, 1949

Synoptic Situation--A very weak pressure gradient existed over the operational area with the Pacific sub-tropical high pressure system extending into California.

Conditions of Seeding--An altocumulus cloud deck was seeded twice. Observations revealed that the deck was interspersed with ice crystal and supercooled water portions at sundry locations along the mountain range from McClellan Air Force Base, Calif., to Reno, Nev. The first seeding, nevertheless was executed in a supercooled portion as evidenced by the appearance of a glory on the cloud deck as the aircraft was flown along the original seeding line; but on the second run, a sun pillar was observed prior to seeding. The two seedings, when combined, resulted in a parallologram pattern. The first seeding was "L-shaped"; then another 'L' pattern was flown so that it would start and terminate at the extremities of the original 'L'. In the second 'L', a single pellet was all that was dropped on the first leg while on the second leg, 48 pellets were released in 90 seconds. Tops of the clouds were near 14,000 ft. m.s.l. with temperatures near -10.0° C. The base was near 13,500-13,700 ft. m.s.l. with temperatures ranging from -8.0° to -9.0° C.

Rate of Seeding--Dry ice pellets were released at the rate of one pound per mile on the first run; on the second run one pellet was dropped on the first leg and 48 pellets were dropped in 90 seconds on the second leg.

Time and Duration of Seeding:

1st Seeding:
1st leg: Heading 060°; 0929:00 PST; 1 minute plus 35 seconds.
2nd leg: Heading 330°; 0930:55 PST; 1 minute plus 30 seconds.
2nd Seeding:
1st leg: Heading 240°; 1017:00 PST; single pellet just before end of leg.
2nd leg: Heading 150°; 1017:30 PST; 1 minute plus 30 seconds.
(All headings are compass headings)

Results--The cloud changed texture immediately after the first seeding, but the second leg did not become as pronounced as the first one. While the results of this run were observed, the water cloud was dissipating naturally within the immediate vicinity; and in one section, this natural dissipation extended right up to the edge of the ice crystal portion (the seeded area). This seeded portion remained while the natural water cloud dissipated.

No results were observed after the second seeding run, but the lack of positive results was not significant since the seeded section was already composed of ice crystals.

No precipitation fell from the seeded portion of the cloud.

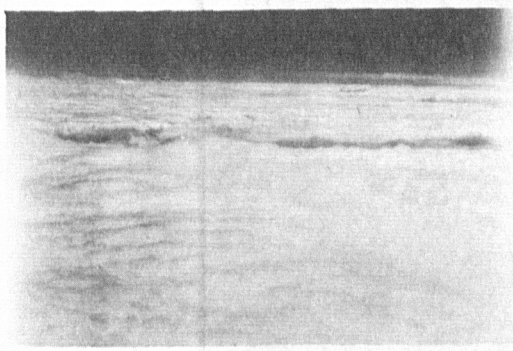


Figure 7.--First seeded area showing change in texture, April 7, 1949.

Method of Verification:

Structural:
1st Seeding: Visual observationa (aerial) and photographs of the seeded cloud (see fig. 7).
2nd Seeding: Visual observations (aerial).

Precipitation:
1st and 2nd Seeding: Visual observations (aerial) and visual observation of the radar scope indicating that no echo formed in the seeded area. Synoptic weather reports very close to the seeded area.

Comments--The results of this mission followed very closely those of March 24, 1949. The natural water cloud dissipated in the immediate vicinity of the seeded area while the ice crystal structure of the seeded area remained little effected. Glories were observed along the seeding path on the first seeding run; and several minutes after seeding, a sun pillar was observed in the area. The first seeded area spread to a maximum width of about 1 mile.

The seeding operations were performed in the vicinity of Carson City, Nev. Natural shower activity was reported in the Donner Summit-Truckee area during progress of the mission, but it was not believed that any precipitation resulted from the seeding operations some 25-35 miles away.

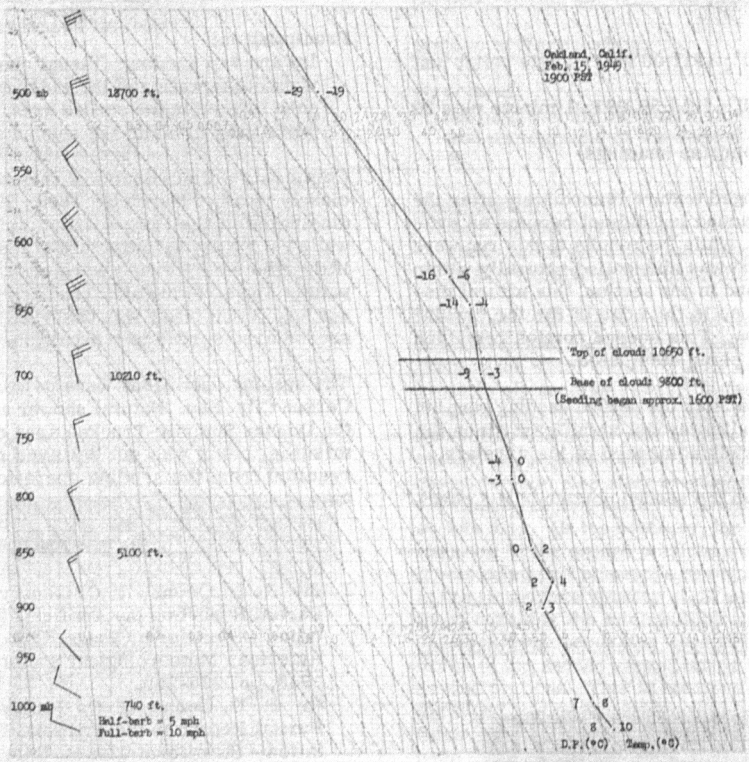
REFERENCES

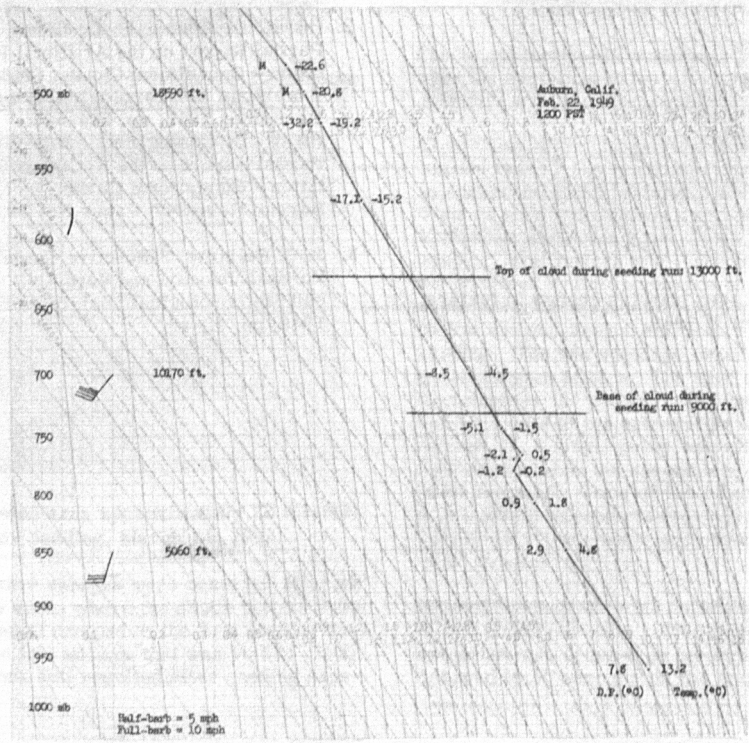
1. (a) R. D. Coons, R. C. Gentry, Ross Gunn, "First Partial Report on the Artificial Production of Precipitation - Stratiform Clouds, Ohio 1948," Bulletin of the American Meteorological Society, vol. 29, No. 5, May 1948, pp. 266-269.
(b) R. D. Coons, R. C. Gentry, Ross Gunn, "First Partial Report on the Artificial Production of Precipitation - Stratiform Clouds, Ohio 1948," U. S. Weather Bureau Research Paper No. 30, August 1948.

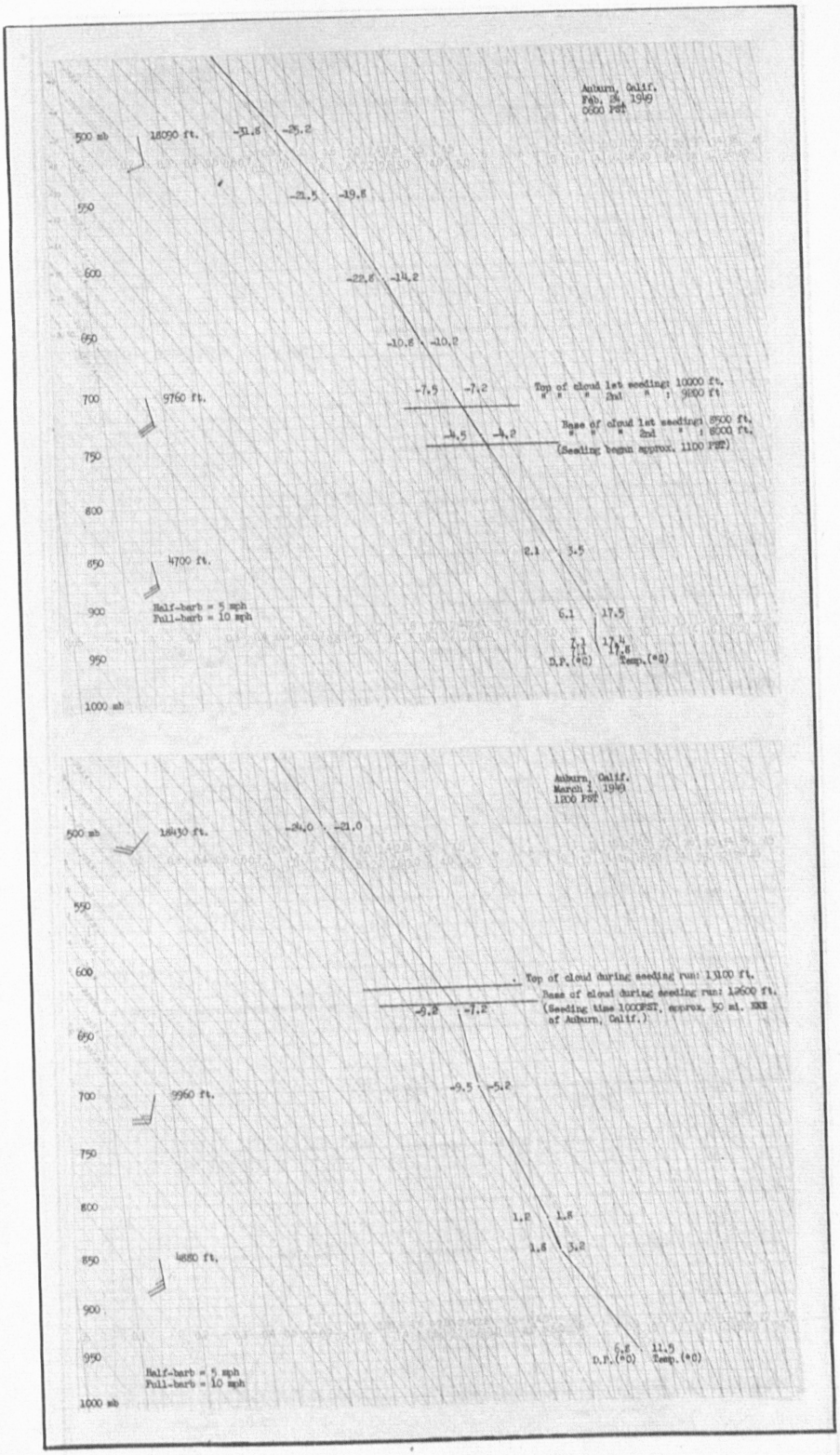
2. (a) R. D. Coons, E. L. Jones, Ross Gunn, "Second Partial Report on the Artificial Production of Precipitation - Cumuliform Clouds, Ohio 1948," Bulletin of the American Meteorological Society, vol. 29, No. 10, December 1948, pp. 544-546.
(b) R. D. Coons, E. L. Jones, Ross Gunn, "Second Partial Report on the Artificial Production of Precipitation - Cumuliform Clouds, Ohio 1948," U. S. Weather Bureau Research Paper No. 31, January 1948.

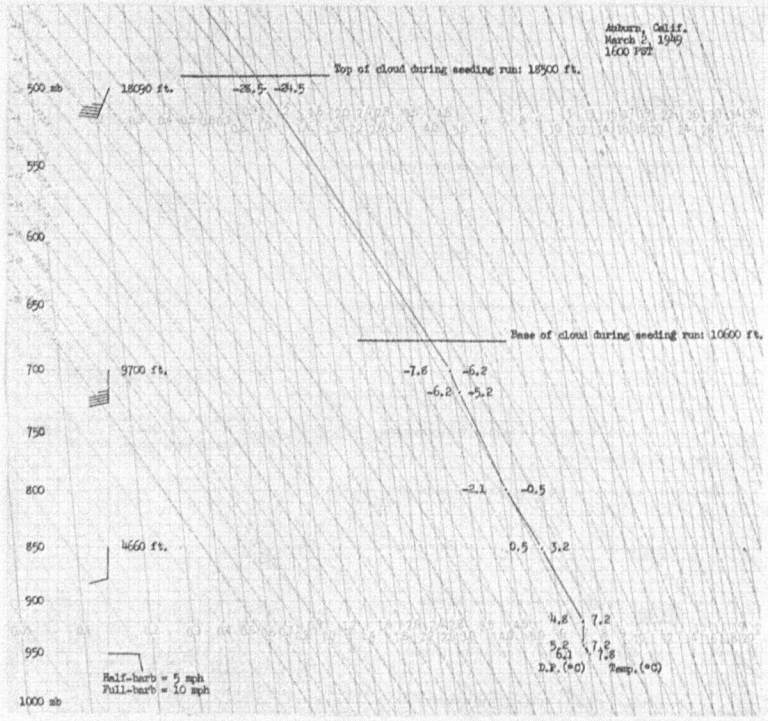
3. J. C. Bellamy, "Objective Calculations of Divergence, Vertical Velocity, and Vorticity," Bulletin of the American Meteorological Society, vol. 30, No. 2, February 1949, pp. 45-49.

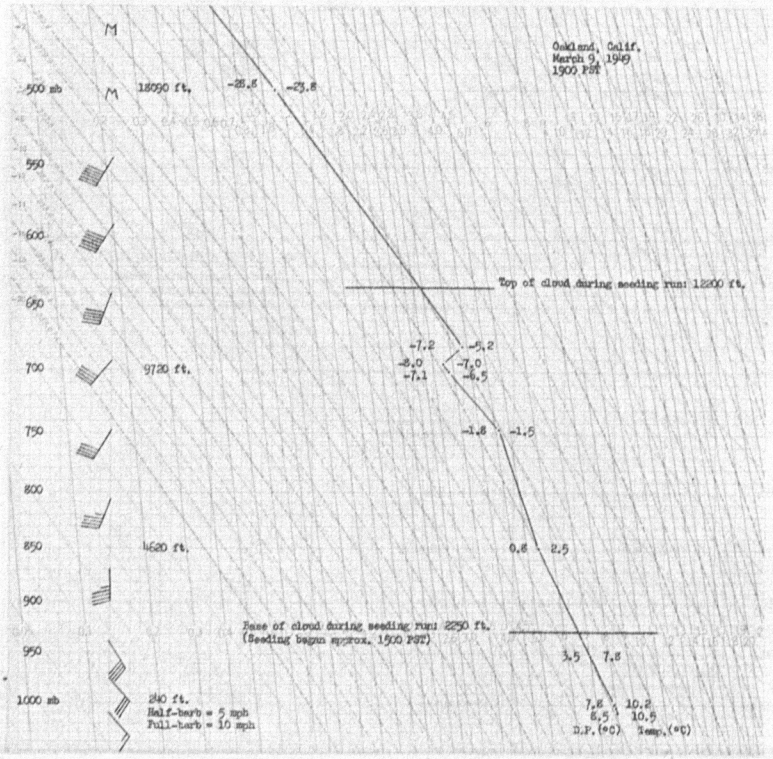
ATMOSPHERIC SOUNDINGS

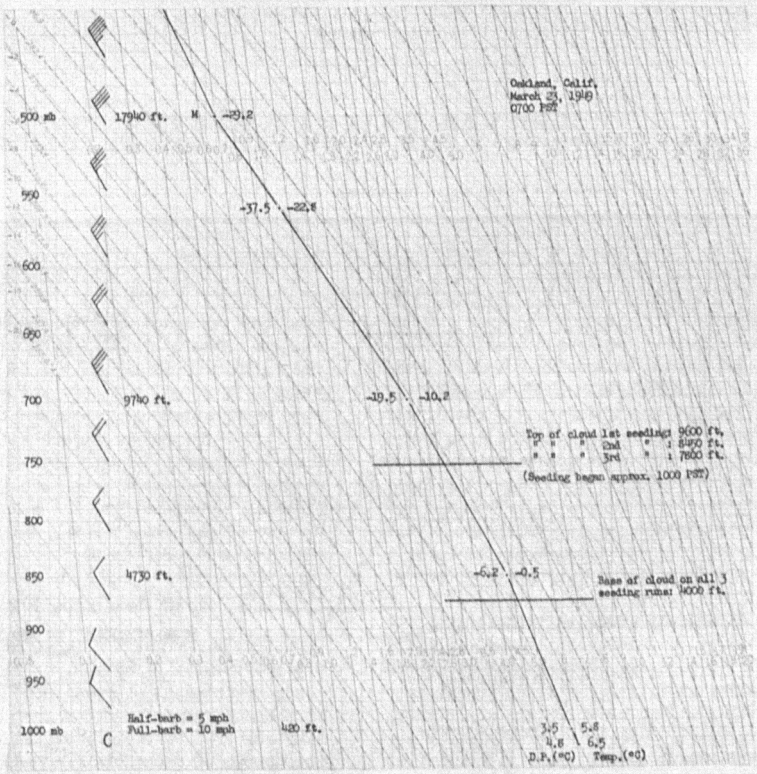


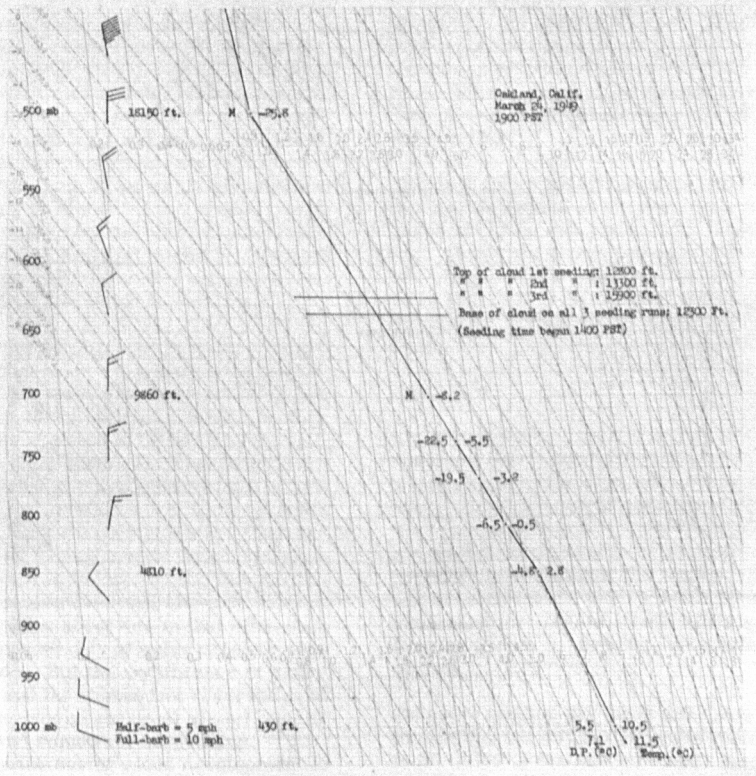


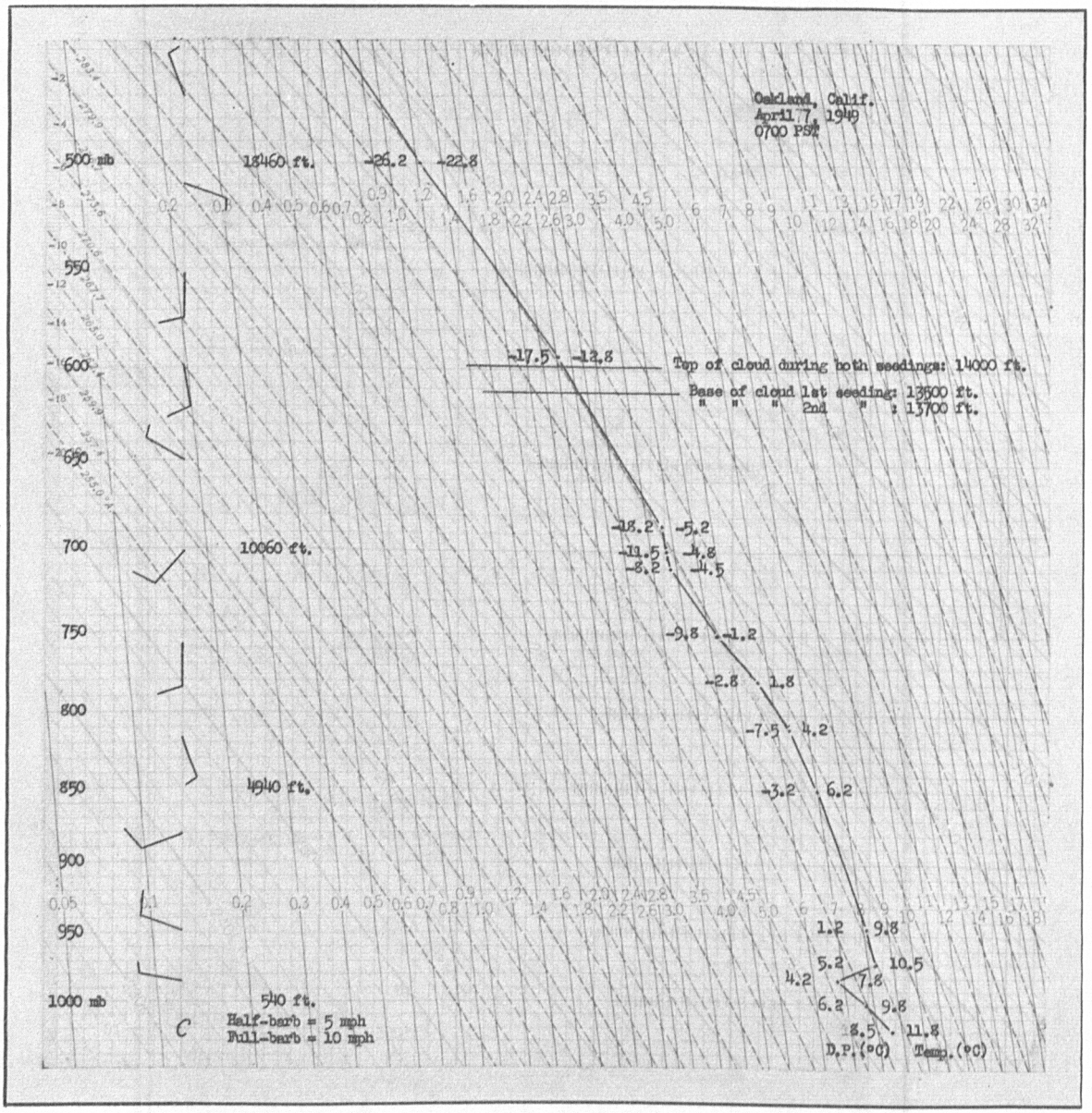

Auburn, Calif.
Feb. 26, 1949
0600 PST
500 mb
18090 ft.
-31.8
-25.2
550
-21.5
-19.8
600
-22.8
-14.2
650
-10.8
-10.2
700
9760 ft.
-7.9
-7.2
Top of cloud 1st seeding: 10000 ft.
" " " 2nd " : 9800 ft
Base of cloud 1st seeding: 8500 ft.
" " " 2nd " : 8000 ft.
(Seeding begun approx. 1100 PST)
750
-4.5
-4.2
800
850
4700 ft.
2.1
3.5
900
Half-barb = 5 mph
Full-barb = 10 mph
6.1
17.5
7.1
17.4
7.1
19.8
950
D.P.(°C)
Temp.(°C)
1000 mb
Auburn, Calif.
March 1, 1949
1200 PST
500 mb
18430 ft.
-24.0
-21.0
550
600
Top of cloud during seeding run: 13100 ft.
Base of cloud during seeding run: 12600 ft.
(Seeding time 1000PST, approx. 50 mi. NNE of Auburn, Calif.)
-8.2
-7.2
650
700
9960 ft.
-9.5
-5.2
750
800
1.2
1.8
1.6
3.2
850
4880 ft.
900
6.2
11.9
950
D.P.(°C)
Temp.(°C)
Half-barb = 5 mph
Full-barb = 10 mph
1000 mb


Auburn, Calif.
March 2, 1949
1600 PST
Top of cloud during seeding run: 18500 ft.
500 mb
18050 ft.
-28.5 -24.5
550
600
650
Base of cloud during seeding run: 10600 ft.
700
9700 ft.
-7.8 -6.2
-6.2 -5.2
750
800
-2.1 -0.5
850
4660 ft.
0.5 3.2
900
4.8 7.2
5.2 7.2
6.1 7.8
D.P. (°C) Temp. (°C)
950
Half-barb = 5 mph
Full-barb = 10 mph
1000 mb


Oakland, Calif.
March 9, 1949
1500 PST
M
500 mb
M
18050 ft.
-28.8 -23.8
550
600
Top of cloud during seeding run: 12200 ft.
650
-7.2 -5.2
700
9720 ft.
-8.0 -7.0
-7.1 -6.5
750
-1.8 -1.5
800
850
4620 ft.
0.8 2.5
900
Base of cloud during seeding run: 2250 ft.
(Seeding began approx. 1500 PST)
950
3.5 7.8
1000 mb
240 ft.
Half-barb = 5 mph
Full-barb = 10 mph
7.8 10.2
8.5 10.9
D.P. (°C) Temp. (°C)


Oakland, Calif.
March 23, 1949
0700 PST
500 mb
17940 ft.
M -29.2
550
-37.5 -22.8
600
650
700
9740 ft.
-19.5 -10.2
Top of cloud 1st seeding: 9600 ft.
" " " 2nd " : 8400 ft.
" " " 3rd " : 7800 ft.
750
(Seeding began approx. 1000 PST)
800
850
4730 ft.
-6.2 -0.5
Base of cloud on all 3 seeding runs: 4000 ft.
900
950
1000 mb
Half-barb = 5 mph
Full-barb = 10 mph
420 ft.
3.5 5.8
4.8 6.5
D.P.(°C) Temp.(°C)


Oakland, Calif.
March 24, 1949
1900 PST
500 mb
18150 ft.
M -25.8
550
600
Top of cloud 1st seeding: 12800 ft.
" " " 2nd " : 13100 ft.
" " " 3rd " : 15900 ft.
Base of cloud on all 3 seeding runs: 12500 ft.
650
(Seeding time began 1400 PST)
700
9860 ft.
M -8.2
-22.5 -5.5
750
-19.5 -3.2
800
-6.5 -0.5
850
4810 ft.
-4.8 2.8
900
950
1000 mb
Half-barb = 5 mph
Full-barb = 10 mph
430 ft.
5.5 10.5
7.1 11.5
D.P.(°C) Temp.(°C)


Oakland, Calif.
April 7, 1949
0700 PST
500 mb
18460 ft.
-26.2 : -22.8
550
600
650
700
10060 ft.
750
800
850
4940 ft.
900
950
1000 mb
540 ft.
Half-barb = 5 mph
Full-barb = 10 mph
-17.5 : -12.8
Top of cloud during both seedings: 14000 ft.
Base of cloud 1st seeding: 13500 ft.
" " " 2nd " : 13700 ft.
-18.2 : -5.2
-11.5 : -4.8
-8.2 : -4.5
-9.8 : -1.2
-2.8 : 1.8
-7.5 : 4.2
-3.2 : 6.2
1.2 : 9.8
5.2 : 10.5
4.2 : 7.8
6.2 : 9.8
8.5 : 11.8
D.P. (°C) Temp. (°C)

FOURTH PARTIAL REPORT: CUMULIFORM CLOUDS - GULF STATES, 1949

INTRODUCTION

In further pursuit of information concerning the artificial production of precipitation from cumulus clouds, tests in cooperation with the U. S. Air Force were carried out during May and June 1949 in the Gulf States area near Mobile, Ala. These tests are a continuation of those conducted by the Cloud Physics Project in Ohio in 1948 [1, 2]. The experiments in the Gulf area seemed necessary to show if the results in the Ohio tests were in any way influenced by the particular type of cloud encountered there. Brookley Air Force Base, Mobile, Ala., was chosen as the base of operations because of the aircraft maintenance facilities available there and because of the high prevalence of semi-tropical cumulus and cumulonimbus in the vicinity.

In planning for the Gulf operation, it was realized that serious difficulties would be encountered in delineating and separating natural effects from those resulting from seeding. Therefore, the same detailed observational techniques as previously described [1, 2] were used. A B-17 was used to perform the seeding and then to observe the results at the top of the cloud, while a C-47 was used to check for precipitation while flying beneath the cloud base. Fortunately available for use was a high-powered 10 cm. control radar which was installed in a bomber aircraft. This radar used from a ground location indicated the locations of both of the project aircraft at all times and detected rain areas whether naturally or artificially produced. It is of utmost importance to consider the confusion and errors that might result in the evaluation of cumulus cloud seedings when a radar aid is not used. Rain from an immediately adjacent unseeded cloud might easily be attributed to a seeded one by the aircraft flying underneath. On the other hand, clouds which were already in the rain stage, as would be indicated by radar echoes from them, might be seeded and the natural rain subsequently observed attributed to seeding.

Altogether 44 seedings into 39 different cumulus clouds, whose tops were supercooled, were made during the period covered by this report. The results of these seedings are strikingly similar to those observed in the 79 Ohio seeding tests [2] although the natural pattern of behavior of the Gulf Coast cumulus seemed to make them somewhat less favorable than the Ohio clouds for the artificial production of precipitation by seeding. Ice crystals would form naturally in these Gulf clouds when they reached just a few thousand feet above the freezing level. Usually when the temperature at the tops of such clouds was below -6° C., natural ice crystals were detected during in-cloud traverses. The interesting and deceiving thing about this is that often such clouds appeared to be composed only of water droplets when observed from the outside. But the occurrence of radar echoes from such clouds and the subsequent observation of ice crystals within them proved external visual observations to be uncertain and somewhat misleading. Thus, there was only a short period during cloud development in which seeding was likely to be effective; i.e. between the time when the cloud reached the freezing level and the time when it reached the natural crystallization level, some 3,000 to 6,000 feet higher.

SUMMARY OF RESULTS

Table 1 summarizes the data and results obtained during the Gulf Coast operation. Rainfall amounts are not indicated in the table because no rain gage network was set up for these tests. However, since without exception clouds dissipated as a result of seeding, the amount of rain which could have fallen from any one of them would be limited by its liquid water content. This would indicate that a maximum of about 0.2 in. of rainfall could have resulted from the seeding of an especially thick cumulus cloud. This maximum amount appears to be reasonable in view of the short duration of these "small showers" as observed both by the C-47 aircraft and the ground radar.

The table indicates that a number of clouds when seeded contained both supercooled water and ice crystals. Such clouds were seeded because none with supercooled water exclusively could be found in the vicinity and, in some few cases, because their external appearance as noted above were those of water clouds. There are three cases listed in Table 1 in which cloud echoes were observed before seeding but in which no ice crystals were noted during the seeding traverse. It is quite possible in each of these few cases that the seeding run was not made directly into the portion of the cloud which produced the radar echo. The few cases of observed ice crystals with no co-existing radar echoes may well be due to the sparseness and small size of such crystals within the clouds at the times of observation.

Tables 2 and 3 briefly summarize the precipitation and dissipation results of the seedings. We have separated the cases of clouds with and without radar echoes before seeding. These two categories are dealt with separately in the two tables. We have not included results from clouds which were observed to be dissipating before seeding in the cloud dissipation summaries of either table. The term, "partial dissipation," as used here means that at least ten percent and as much as ninety percent of the seeded cloud dissipated.

All of the clouds covered in Table 3 showed pre-seeding radar echoes from which it can be inferred that they contained ice crystals along with supercooled water observed in all clouds seeded during these tests. From the data in the table, it seems apparent that seeding hastened the process of dissipation in these partly self-nucleated clouds probably by increasing the number of nuclei available. If left unseeded, such clouds would probably become heavily nucleated (or crystallized) after some period of time ("aging period"). Seeding, then, effectively shortens this period.

On every seeding day there were natural showers and often thunderstorms within a 100-mile radius of Mobile and within 30 miles of the seeded cloud. Because of this fact and considering the data presented above, it seems a logical conclusion that seeding, usually by stopping the development of cumulus soon after they reach the freezing level, possibly interferes with the growth of some few of them to full

Table 1.--Summary of data and results of seeding 39 cumuliform clouds, Gulf States, 1949.

Date	Base of Clouds (ft.)	Top of Seeded Cloud (ft.)	Temperature Vicinity Bases (°C)	Temperature Vicinity Tops (°C)	Freezing Level of Environment (ft.)[1]	Seeding Altitude (ft.)	Clouds Supercooled	Ice Crystals Observed	Pounds CO_2 Per Mile	Partial Dissipation Only	Complete Dissipation	Only Building After Seeding	Status of Cloud[2]	Cloud Echo Before Seeding	Cloud Echo After Seeding	Light Rain Before or After Seeding Without Echo	Rainfall from Cloud	Natural Showers within 30 Miles
1949																		
May 9	5600	16000	13	-5	12800	14900	Yes	Yes	5	Yes	No	No	B	No	Yes	No	Virga	Yes
9	5600	17000	13	-8	12800	15500	Yes	No	5	Yes	No	No	B	Yes	Yes?	No	Trace	Yes
9	5500	15000	13	-3	12800	15000	Yes?	?	5	Yes	No	No	S	No	No	No	None	Yes
18	4000	17500	18	-6	14200	16100	Yes	Yes	5	Yes	No	No	P	Yes	Yes	No	(6)	Yes
23	4500	18500	16	-10	13900	17000	Yes	No	5	Yes	No	No	S	No	No	No	None	Yes
23	4500	18000	16	-8	13900	16500	Yes	Yes	5	Yes	No	No	B	No	No	No	None	Yes
23	4500	16900	16	-7	13900	16800	Yes	?	4	Yes	No	No	B	Yes	Yes	No	(6)	Yes
23	4500	18000	16	-8	13900	17000	Yes	No	4	Yes	No	No	S	No	No	No	None	Yes
23	4500	16000	16	-5	13900	15700	Yes	No	4	Yes	No	No	B	Yes	Yes	No	(6)	Yes
24	3000	16600	20	-5	13700	17200	Yes?	?	5	Yes	No	No	B	Yes	Yes	No	Virga	Yes
24	3000	18000	20	-9	13700	17200	Yes	No	5	Yes	No	No	E	No	No	No	None	Yes
24	3000	18000	20	-9	13700	17100	Yes	No	5	Yes	No	No	P	Yes	Yes	No	(6)	Yes
27	5500	19000	15	-9	12300	17600	Yes	No	5	Yes	No	No	B	No	No	No	None	Yes
27	5500	17500	15	-8	12300	18100	Yes?	No	5	Yes	No	No	D	No	No	No	None	Yes
27	5500	25000	15	-25	12300	18000	Yes	Yes	5	Yes	No	No	B	No	Yes	No	(6)	Yes
27	5500	20000	15	-11	12300	18000	Yes	No	5	Yes	No	No	P	No	No	No	None	Yes
27	5500	19000	15	-9	12300	18500	Yes	No	5	Yes	No	No	D	No	No	No	None	Yes
June 1	4000	14900	21	-2	13700	14800	Yes	Yes	5	No	Yes	No	B	Yes	Yes	No	(6)	Yes
1	4000	16500	21	-4	13700	15000	Yes	Yes	5	Yes	No	No	B	Yes	Yes	No	(6)	Yes
1	4000	18000	21	5	13700	15500	Yes	Yes	[3]20	Yes	No	No	B	Yes	Yes	No	(6)	Yes
5	5600	15000	16	-2	13600	15000	Yes	Yes	5	Yes	No	No	B	No	Yes	No	Virga	Yes
5	5600	15000	16	-2	13600	15000	Yes	No	4	Yes	No	No	D	No	No	No	None	Yes
5	5600	15000	16	-2	13600	15000	Yes	No	4	Yes	No	No	D	No	No	No	None	Yes
5	5600	17000	16	-4	13600	17000	Yes	Yes	5	Yes	No	No	P	Yes	Yes	No	(6)	Yes
5	5600	18000	16	-6	13600	17000	Yes	Yes	5	Yes	No	No	B	No	Yes	No	Trace?	Yes
6	5000	20000	18	-10	13700	18080	Yes	Yes	5	Yes	No	No	P	Yes	Yes	No	(6)	Yes
6	5000	18000	16	-7	13700	18500	Yes?	?	4	Yes	No	No	B	No	No	After	Virga	Yes
6	5000	17000	18	-5	13700	16400	Yes	No	5	Yes	No	No	P	No	No	After	Virga	Yes
7	5000	22000	17	-16	12800	19520	Yes	Yes	5	Yes	No	No	D	No	Yes	No	Virga	Yes
7	5000	22000	17	-16	12800	19450	Yes	Yes	5	Yes	No	No	D	Yes	Yes	No	Virga	Yes
7	5000	24000	17	-25	12800	19400	Yes	No	5	Yes	No	No	P	No	Yes	No	Virga	Yes
8	3500	25000	21	-25	13400	20200	Yes	Yes	5	Yes	No	No	B	(4)	(5)	(5)	(6)	Yes
8	3500	22000	21	-15	13400	20500	Yes	No	5	Yes	No	No	B	(4)	(5)	(5)	Virga	Yes
8	3500	19000	21	-10	13400	19000	Yes?	?	5	Yes	No	No	D	No	No	No	None	Yes
9	2500	17900	22	-7	13500	17490	Yes	No	5	Yes	No	No	B	No	Yes	No	Virga	Yes
10	1500	20000	25	-9	14600	17560	Yes	Yes	5	Yes	No	No	B	Yes	Yes	No	(6)	Yes
10	1500	17500	25	-6	14600	17500	Yes	No	4	Yes	No	No	B	No	Yes	No	Virga	Yes
13	2500	18000	22	-6	13900	18480	Yes?	?	5	Yes	No	No	B	No	No	After	Virga	Yes
13	2500	19500	22	-8	13900	18480	Yes	Yes	5	Yes	No	No	B	No	No	After	Virga	Yes

1. Estimated (APOB).
2. B building; D dissipating; S stagnant.
3. Instantaneous drop.
4. Unknown.
5. No radar observations.
6. Small shower reached ground; no rain gage in proper location.

scale thunderstorms. All of our observations seem consistent with this conclusion. Seeding, then, might actually be a deterrent to the production of precipitation over any particular area. It apparently inhibits the growth of cumulus clouds by initiating premature downdrafts of ice crystals which subsequently choke off the necessary moisture inflow at lower altitudes and at lesser stages of development than those decreed by nature.

Table 2.--Precipitation and dissipation results of seeding 24 cumuliform clouds with no previous rain echo

Total Number	24
Echoes Resulted from Seeding	8
Rain Produced[1]	12
Natural Echoes within 30 miles	24
Cloud Building[2] at Time of Seeding	18
Cloud Building only after Seeding	0
Partial Dissipation of Building[2] Cloud	18
Complete Dissipation of Building[2] Cloud	0

[1] Small showers and in some cases only virga.

[2] Includes clouds indicated in table 1 as building (B) or stagnating (S).

Table 3.--Dissipation results of seeding 13 cumuliform clouds with previous rain echo

Total Number	13
Cloud Building at Time of Seeding	12
Cloud Building only after Seeding	0
Partial Dissipation of Building Cloud	11
Complete Dissipation of Building Cloud	1

DESCRIPTION OF INDIVIDUAL SEEDING MISSIONS

Cloud Seeding Mission of May 9, 1949

Synoptic Situation--The seeding operations were accomplished in the warm sector of a low pressure system centered in southeastern Missouri at 1230 CST. The associated cold front was located in eastern Arkansas and northwestern Louisiana. A large area of eastern Mississippi and western Alabama recorded precipitation on May 9, 1949, but the rainfall was generally light.

Conditions of Seeding--All three seeding runs were made within a 20 mile radius of Brookley Air Force Base. Scattered showers were observed in the area throughout the mission. Observations in flight revealed that most of the cumuli were reaching 11,000 ft. to 12,000 ft. m.s.l. and then passing naturally into the dissipating stage. All seeded clouds, however, were reaching heights ranging from 15,000 ft. to 17,000 ft. m.s.l. The temperatures in the vicinity of the clouds ranged from +13.0° C. at the base to -5.0°, -8.0°, and -3.0° respectively near the tops on the three runs. The first two clouds were flown through on the seeding run while the third run was executed over the top of the cloud. Clear icing was observed in all clouds flown through, but in addition rime icing was observed in the 2nd tower of the first cloud.

Rate of Seeding--Dry ice pellets were dropped into the clouds at the rate of 5 pounds per mile on all seeding runs.

Time and Duration of Seeding:

1st Seeding: 1308:15 CST; 1 minute plus 5 seconds.
2nd Seeding: 1352:20 CST; 1 minute plus 32 seconds.
3rd Seeding: 1437:30 CST; 0 minutes plus 40 seconds.

Results--The first seeding run was through two towers of a building cumulus (fig. 1). The cloud dissipated about 75-80 percent after seeding, but comparative observations were made of similar clouds in the area and identical dissipation results were observed. The seeded cloud did change texture, however; therefore, there is a possibility that the dissipation was hastened as a result of seeding.

A single tower was seeded on the second seeding run (fig. 2). The cloud changed texture slightly and the top dissipated about 60-75 percent.

The third seeding was northwest of Brookley Air Force Base. About 90 percent of the cloud dissipated after seeding, but no texture change was observed (fig. 3). Since the top of the cloud was very close to the freezing level it is possible that it may not have been supercooled. It's dissipation may have resulted from natural causes since it followed the same cycle as neighboring clouds and did not display the usual seeding result characteristics that have been observed many times before in supercooled clouds.
A small faint cloud echo formed in the seeded area about 8 minutes after the first seeding, but it could not be definitely determined whether it was the result of seeding or not. Two towers were seeded on the run and only rime ice was the result of natural developments instead of artificial modifications. The low observation plane was flown under the cloud and a few drops of rain were reported about 1320 CST. Since the precipitation was light and the echo was very faint, it is doubtful that the rain reached the ground.

It is not known whether an echo existed at the time of the second seeding because the run was accomplished directly over the Air Force Base and possible echoes were obscured by ground clutter. A faint echo was observed, however, about 1402 CST as the cloud moved out of the ground clutter. Verification that the echo was from the seeded cloud was determined by visual observations of landmarks. The observers in the low observation plane reported the rain to be moderately intense, well concentrated, and reaching the surface. It should be mentioned, however, that ground observers reported light rain from the cloud just as the seeding run was made.

No precipitation was observed falling from the cloud after the third seeding run.

Method of Verification:

Structural:
1st, 2nd and 3rd Seedings: Visual observations (aerial) and photographs of the seeded cloud (figs. 1, 2, and 3).

Precipitation:
1st and 3rd Seedings: Visual observations (aerial) plus ground radar observations (visual and photographic).
2nd Seeding: Visual observations (aerial) plus ground radar observations (visual and photographic); ground observations (visual).

Comments--Even though a noticeable amount of dissipation was observed after all seedings (figs. 1, 2 and 3), the total changes may not have been entirely the result of seeding. It was noted that other clouds were also dissipating naturally after reaching levels above 11,000-12,000 ft. m.s.l.; therefore it is possible that the seedings only hastened the natural processes. All precipitation after seedings was equally as questionable as dissipation results. Since rime ice was observed in the second tower of the first cloud, it can not be definitely determined whether or not the cloud was developing naturally into the rain stage at the time of seeding. The rime icing does indicate very strongly that natural crystallization and sublimation were already in progress at the time of the seeding run; therefore it is highly probable that rain would have fallen without the aid of artificial nucleation. The second cloud was hit just at the time natural rain was about to be released; consequently the occurrence of the precipitation after seeding is not too significant. The lack of positive results after the 3rd seeding is also insignificant since the top of the cloud was so close to the freezing level.

The cloud easily could have been non-supercooled; therefore positive results should not have been expected. It should be mentioned that a few natural showers were occurring, nevertheless, within 20 miles of all seeded clouds and the showers continued throughout the mission.

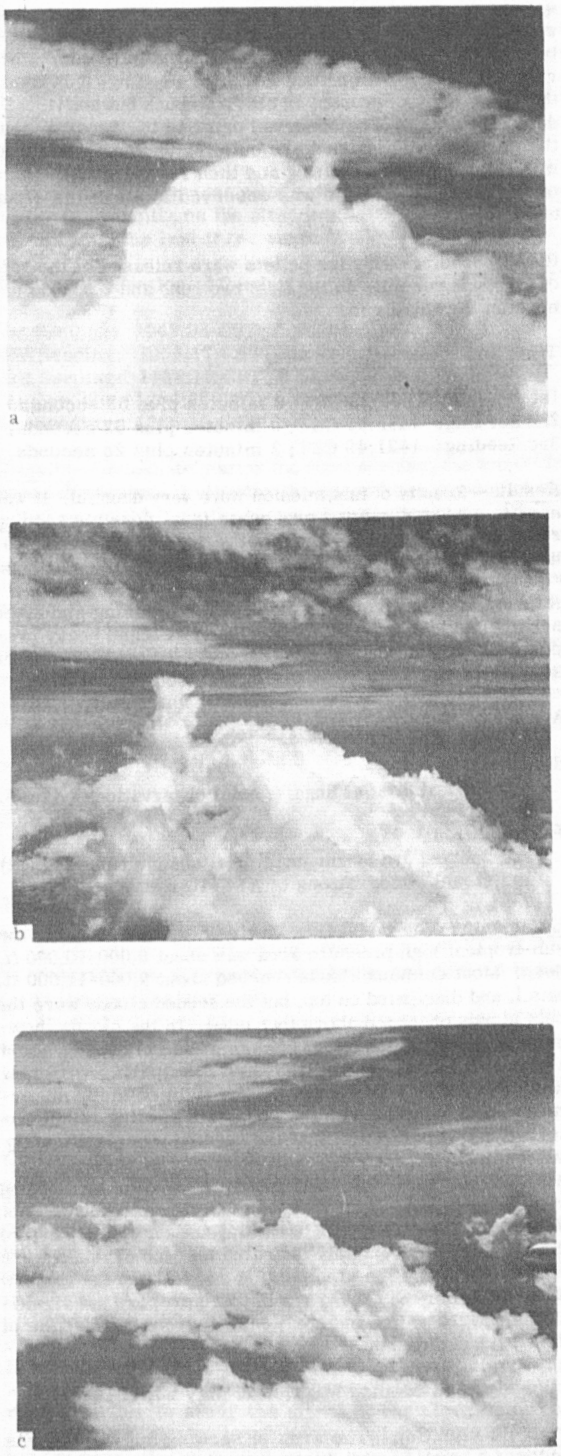


Figure 1.--First seeded cloud, May 9, 1949.
(a) Before seeding; 1308 CST; altitude 14,600 ft.; direction 330°.
(b) After seeding; 1320 CST; altitude 15,600 ft.; direction 150°.
(c) After seeding; 1332 CST; altitude 15,300 ft.; direction 220°.

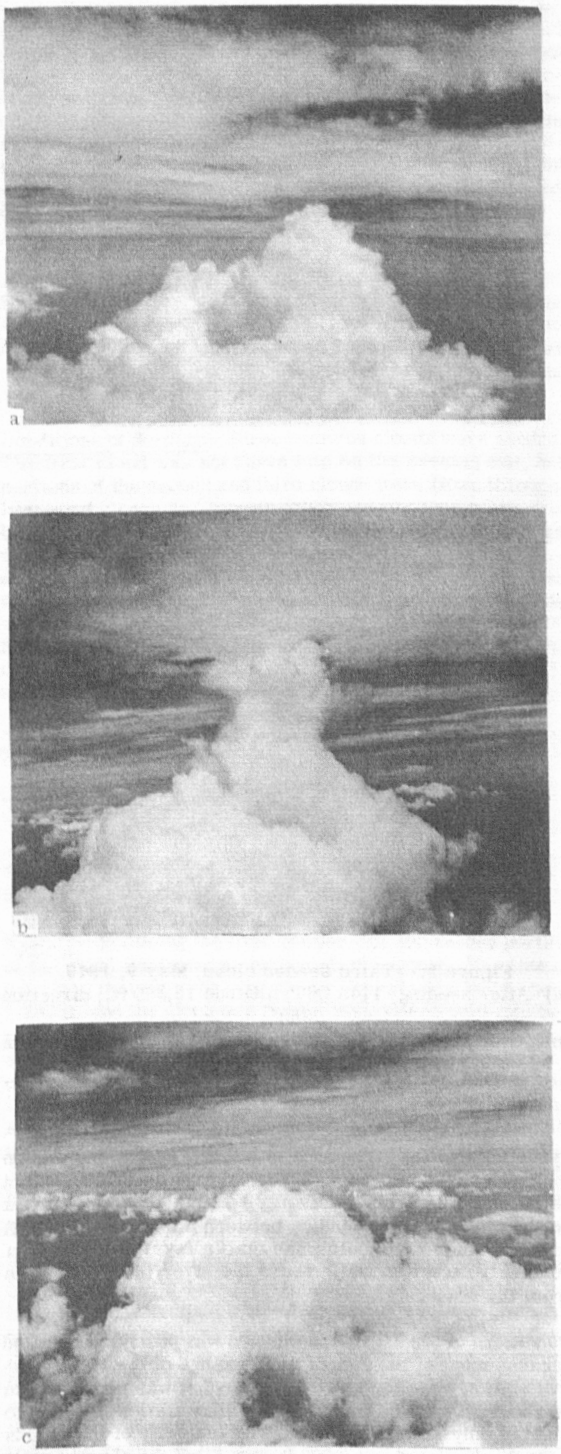
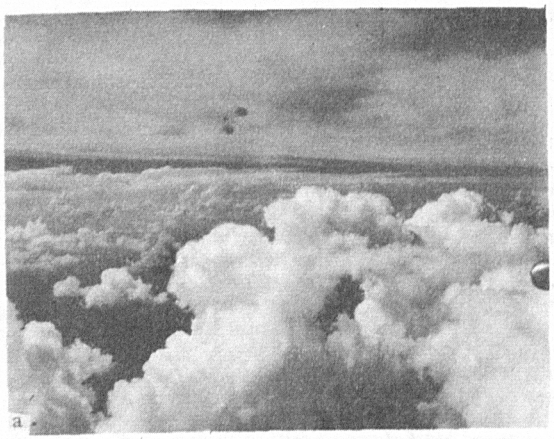


Figure 2.--Second seeded cloud, May 9, 1949.
(a) Before seeding; 1350 CST; altitude 15,500 ft.; direction 150°.
(b) After seeding; 1358 CST; altitude 15,500 ft.; direction 100°.
(c) After seeding; 1409 CST; altitude 15,500 ft.; direction 100°.



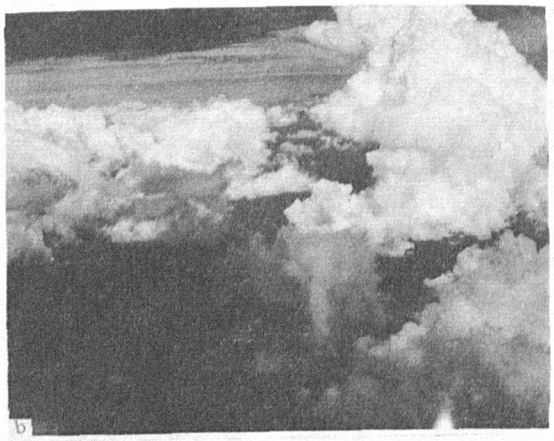


Figure 3.--Third seeded cloud, May 9, 1949.
(a) After seeding; 1440 CST; altitude 15,300 ft.; direction 360°.
(b) After seeding; 1453 CST; altitude 15,000 ft.; direction 100°.

Cloud Seeding Mission of May 18, 1949

Synoptic Situation--The area of seeding operations was on the western side of the sub-tropical high pressure system centered in the Atlantic Ocean. A stable area was evident on the atmospheric sounding between 5,000 and 10,000 ft. m.s.l. Winds aloft below the stable layer were from a southerly direction while above the layer the winds were from the north.

Conditions of Seeding--This mission was poorly coordinated because most of the cumuli within range of the radar control station were too small for study. It was necessary to go about 110-130 miles from the radar station in order to find the only suitable clouds. The majority of the clouds were dissipating above 9,000 ft. m.s.l. but the clouds finally chosen for study reached 17,500 ft. m.s.l. Temperatures in the vicinity of the clouds ranged from +18.0° C. at the bases to -6.0° C. near the tops. The clouds were very easy to spot after seeding because they were the only ones of that size in the area. All seeding runs were made in a group of cumulus towers that merged into the same cloud base; therefore, for all practical purposes, the same cloud was seeded on all three seeding runs - just different portions were attacked. Only clear icing was observed on the first two runs but rime ice was observed on the third run. Since rain was falling both before and after seeding, it is likely that rime ice was present on all three runs but not visually detected. It was also observed prior to the seedings that the prospective towers were building to about 18,000 ft. m.s.l., partially dissipating and then regenerating. Light to moderate turbulence was observed in all of the cloud towers.

Rate of Seeding--Dry ice pellets were released at the rate of 5 pounds per mile on the first two runs and 6 pounds per mile on the third run.

Time and Duration of Seeding:

1st Seeding: 1406:22 CST; 0 minutes plus 53 seconds.
2nd Seeding: 1415:51 CST; 0 minutes plus 52 seconds.
3rd Seeding: 1421:49 CST; 2 minutes plus 26 seconds.

Results--Results of this mission were very doubtful. It was hard to separate natural processes from possible seeding results; nevertheless, the observers felt that a small amount of dissipation may have resulted from the seedings.

Rain was falling from the cloud before, during and after seeding; and its intensity occasionally reached heavy proportions. Cloud echoes were also observed before and after seeding on the APS-10 radar in the seeding aircraft.

Method of Verification:

Structural:
1st, 2nd and 3rd Seedings: Aerial observations (visual).

Precipitation:
1st, 2nd and 3rd Seedings: Aerial observations (visual) and visual observations of APS-10 radar scope.

Comments--The moist flow of air on the west side of the sub-tropical high pressure area was about 9,000-10,000 ft. deep. Most cumulus clouds reached about 9,000-11,000 ft. m.s.l. and dissipated on top, but the seeded clouds were the only clouds observed above that level. In the clouds, however, it was observed that towers were building to about 17,000-18,000 ft. m.s.l. and then dissipating with new towers forming thereafter. In the light of these observations and together with the uncertain seeding result observations, it is doubtful that the seeding was significantly successful.
Although only clear icing was reported on two of the seeding runs, it is possible that rime ice also existed but was not observed. The occurrence of natural shower activity before the seeding runs certainly indicated that ice crystals were already present. The precipitation that fell and the rainbow observed under the seeded cloud, therefore, are not significant since the rain was already in progress at the time of the first seeding run.

Cloud Seeding Mission of May 23, 1949

Synoptic Situation--The area of seeding operations was south of a weak frontal system running east-west across northern Alabama at 1230 CST. Thundershowers were reported in the frontal zone. A weak high pressure center was located in the eastern Gulf of Mexico which resulted in southwesterly flow of air over the seeding area.

Conditions of Seeding--Five seeding runs were made into bulging cumulus tops. Clear icing was encountered on all

runs and several showers were noted in the immediate vicinity of all seeded clouds. In fact, cloud echoes from the seeded clouds on the fifth seeding and third seeding were observed on the radar scope prior to the seeding runs. Turbulence was also observed in every cloud seeded. Temperatures ranged from +16.0° C. near the base to -10.0° C. near the tops.

Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on the first two seedings and 4 pounds per mile on the last three runs.

Time and Duration of Seeding:

1st Seeding: 1043:05 CST; 0 minutes plus 38 seconds.
2nd Seeding: 1058:17 CST; 0 minutes plus 58 seconds.
3rd Seeding: 1138:15 CST; 0 minutes plus 50 seconds.
4th Seeding: 1204:25 CST; 1 minute plus 15 seconds.
5th Seeding: 1226:10 CST; 0 minutes plus 30 seconds.

Results--Immediately after the first seeding, the top of the cloud dissipated. Following the second run, the top of the cloud separated from the base and dissipated at the seeding level while the lower part of the cloud remained unchanged and the upper portion became suspended ice crystals. The identical process was repeated after all of the other seeding runs.

Radar echoes were observed prior to the third and fifth seedings; therefore, the occurrence of precipitation after those runs is not significant. No precipitation was observed as a result of the other seedings.

Method of Verification:

Structural:
1st, 2nd, 3rd, 4th and 5th Seedings: Visual observations (aerial).

Precipitation:
1st Seeding: Visual observations (ground).
2nd Seeding: Visual observations (ground) and visual observations of ground radar scope and APS-10 radar in the seeding aircraft.
3rd and 4th Seedings: Visual observations and photographs of the ground radar scope and visual observations of the APS-10 radar scope.
5th Seeding: Visual observations of the ground radar scope.

Comments--Although dissipation was observed in the seeded clouds at the seeding level with suspended ice crystals remaining above the seeding altitude, the total changes may not be entirely significant. Numerous clouds within the immediate vicinity of the seeded clouds were observed to pass through identical cycles. In fact, one cloud very close to the first seeded cloud was investigated and compared with the seeded cloud. A run through the ice crystal veil of the unseeded cloud revealed that some snow flakes were falling from that portion. Several clouds that were similar to the seeded ones were flown through on dry runs in order to study the effect of the aircraft on the clouds. Some dissipation was observed following the runs, but the characteristic split in the clouds never appeared, and the dissipation observed was of less magnitude and permanency than that following the dry ice runs.

No significant precipitation was observed after any of the seeding runs even though natural showers and thunderstorms were observed within 5-20 miles of the seeded clouds. A rainshower was observed at Brookley Air Force Base after the 2nd seeding, but ground, aerial, and radar observations indicated that the shower was from a cloud very close to the seeded cloud. Radar returns were evident before, during, and after the third and fifth seedings; therefore the rain that fell is not significant. It was also observed that other natural echoes close by passed into the dissipation stage along with the seeded echoes. A comparison of the rates of dissipation indicated that the seeding did not noticeably affect the dissipation rates of the seeded echoes.

Cloud Seeding Mission of May 24, 1949

Synoptic Situation--The area of seeding operations was north of a weak east-west cold front located across the northern Gulf of Mexico. A weak high pressure area was centered over western Tennessee. The pressure gradient was very weak.

Conditions of Seeding--Three cumulus clouds were seeded. The first cloud was not flown into on the seeding run, but portions of the second and third clouds were flown through. Light turbulence and icing conditions were encountered in both clouds that were flown through. All three seedings were executed very close to natural thunderstorm conditions which added confusion and difficulty to accurate observations of seeding results. The bases of the clouds were near 3,000 ft. m.s.l. and the tops varied from 16,600 ft. to 18,000 ft. m.s.l. Temperatures in the vicinity of the clouds ranged from +20.0° C. at the bases to -5.0°, -9.0°, and -9.0° C. respectively near the tops on the seeding runs.

Rate of Seeding--Dry ice pellets were released at the rate of 5 pounds per mile on all seeding runs.

Time and Duration of Seeding:

1st Seeding: 1035:20 CST; 1 minute plus 15 seconds.
2nd Seeding: 1051:05 CST; 0 minutes plus 50 seconds.
3rd Seeding: 1105:13 CST; 1 minute plus 4 seconds.

Results--Following the first seeding run, the seeded portion of the cloud dissipated an estimated 30 percent. The side of the cloud that was not seeded was observed to build about 1,200 ft. and the cloud was finally observed to split into two parts. Final observation revealed that a portion of the unseeded section also dissipated. The second cloud became confused with other clouds close by soon after seeding, but it was believed also to have split into two parts with one side building slightly. Following the third seeding (fig. 4), the part of the cloud that was flown over remained unchanged. The tower that was flown through dissipated leaving only wisps of ice crystal cloud at the seeding altitude.

The low observation plane was not used on this mission, but the presence of a radar echo before seeding prior to the first run indicated that a small amount of rain was probably falling before the run. No radar return was observed from the second cloud; therefore it was assumed that no precipitation fell. The third run was into the north side of an already existing echo; therefore the rainbow observed below the cloud immediately after the third run was not believed to be the result of seeding.

Method of Verification:

Structural:
1st and 2nd Seedings: Visual observations (aerial).
3rd Seeding: Visual observations (aerial) and photographs (fig. 4).

Precipitation:

1st Seeding: Visual observations of radar scope in seeding aircraft and CPS-20 radar scope.

2nd and 3rd Seedings: Visual observations and photographs of ground radar scope.

Comments--Icing conditions and turbulence were observed in all clouds flown through, and some texture change was observed after all seeding runs. The amounts of dissipation may be significant since clear icing (an indication of supercooled water) was encountered on the seeding runs. The observers, however, were not absolutely sure of their observations. The seeded clouds were so close to natural thundershower activity that the clouds became confused and intermingled with neighboring clouds, and considerable difficulty was experienced in trying to observe seeding results.

A radar echo was observed on the radar scope in the seeding aircraft prior to the first run; therefore it is possible that some precipitation was falling at the time the seeding was performed. The echo was observed to split into two parts after seeding and the same process was observed visually in the cloud itself. Since no echo was observed on the ground radar scope before or after seeding, however, the rain must have been very light and it probably did not reach the ground. No echo was observed from the seeded portion of the second cloud, but the third run was into the north side of an already existing echo. It was also observed that another small echo developed immediately north of the seeded line a short time after the third seeding. Visual observations of building in that area, however, substantiated the fact that the echo was from an unseeded section of the cloud. Other clouds were giving echo returns within 10 miles of all seeded clouds. A rainbow was also observed immediately after the third seeding; but in the light of the foregoing observations, it is doubtful that the rain was the result of seeding. The time-lapse between seeding time and the time the rainbow was first observed was not sufficient to allow the seeding effects at the top of the cloud to be reflected in conditions observed at the base - another indication that the rain was not the result of seeding.

Cloud Seeding Mission of May 27, 1949

Synoptic Situation--The area of seeding operations was south of a weak stationary front located east-west through central Alabama. The pressure gradient was very weak. Scattered showers were reported at 1230 CST along the frontal zone.

Conditions of Seeding--Five cumulus clouds were seeded on six seeding runs. All of the clouds were supercooled but rime icing was also encountered on the third and fourth seeding runs. All seedings were accomplished 25-30 miles

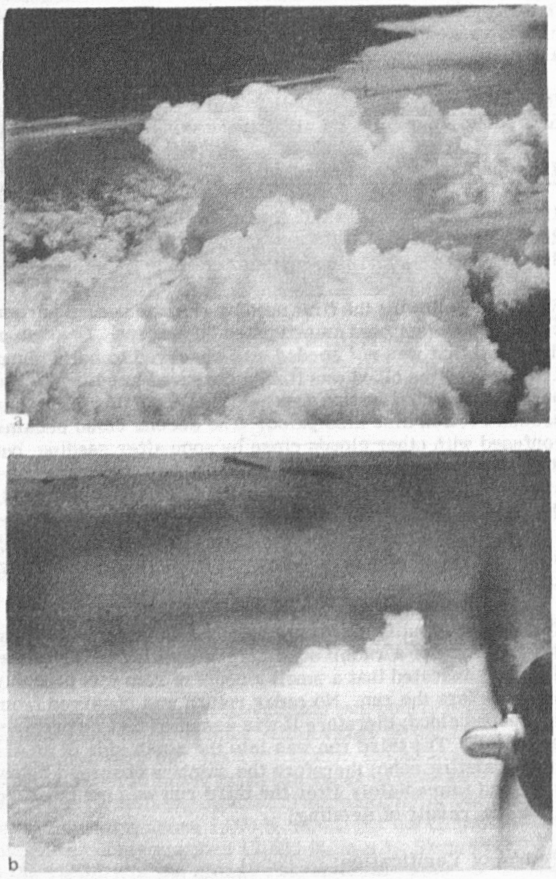


Figure 4.--Third seeded cloud, May 24, 1949.
(a) Before seeding; 1105 CST; altitude 17,300 ft.; direction 100°.
(b) After seeding; 1108 CST; altitude 17,400 ft.; direction 360°.

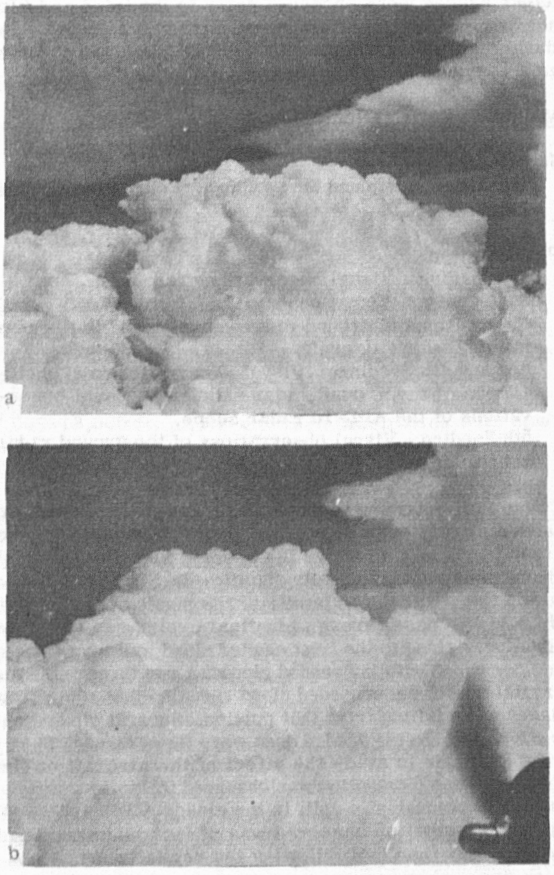


Figure 5.--First seeded cloud, May 27, 1949.
(a) Before seeding; 1323 CST; altitude 17,700 ft.; direction 120°.
(b) After seeding; 1335 CST; altitude 18,200 ft.; direction 120°.

west-northwest of Brookley Air Force Base and very close to existing thundershower activity. Light to moderate turbulence was encountered in all clouds flown through. The bases of the clouds were near 5,500 ft. m.s.l. and the tops ranged from 17,500 ft. to 25,000 ft. m.s.l. Temperatures near the bases were +15.0° C. and near the tops the temperatures varies from -8.0° to -25.0° C.
Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on all seeding runs.

Time and Duration of Seeding:

1st Seeding: 1324:00 CST; 0 minutes plus 25 seconds.
2nd Seeding: 1337:47 CST; 0 minutes plus 38 seconds.
3rd Seeding: 1348:15 CST; 0 minutes plus 50 seconds.
4th Seeding: 1405:00 CST; 1 minute plus 35 seconds.
5th Seeding: 1440:55 CST; 0 minutes plus 38 seconds.
6th Seeding: 1455:35 CST; 0 minutes plus 48 seconds.

Results--A building cumulus was seeded on the first run (fig. 5). The top was slow in responding to the seeding, but it finally changed texture and the top dissipated. A short time later, however, the cloud regenerated and built to heights greater than that observed on the seeding run. The cloud finally merged with the anvil of a nearby thunderstorm and was lost.

Following the second seeding (fig. 6) about 75 percent of the cloud dissipated; but it is doubtful that the total amount of dissipation observed was entirely the result of seeding. The third and fourth seedings were into the same cloud. Following the third seeding (fig. 7) dissipation and change in texture were noted in the eastern section of the cloud. At the same time, the western end of the cloud built up. The fourth run was into the building western section (fig. 8). (This portion was also seeded on the third run but the ice was dropped from above the cloud top.) Following the fourth run into the tower, that section dissipated in the same manner as the eastern part had done following the third seeding run. Immediately west of the fourth seeded area, a tower built up thereby causing confusion in trying to observe the final results of the fourth run. Following the fifth seeding into a building cumulus (fig. 9), about 75 percent of the cloud was estimated to have dissipated. The sixth seeding resulted in about 90 percent of the cloud dissipating (fig. 10).

No precipitation was observed to fall from the seeded clouds before, during, or after seeding on the 1st, 2nd, 5th, and 6th seeding runs. Rain was observed on the periphery of the third cloud shortly after the seeding run and a small echo was observed on the radar scope in the eastern portion of the cloud about 3 minutes after the seeding. Another echo then formed in the western section between the time of the third and fourth seeding runs; therefore the portion that was seeded on the fourth run was already showing an echo before the cloud was treated.

Method of Verification:

Structural:
1st, 2nd, 3rd, 4th, 5th and 6th Seedings: Visual observations and photographs (figs. 5 - 10).

Precipitation:
1st, 2nd, 3rd, and 4th Seedings: Visual observations (aerial) plus visual observations and photographs of the

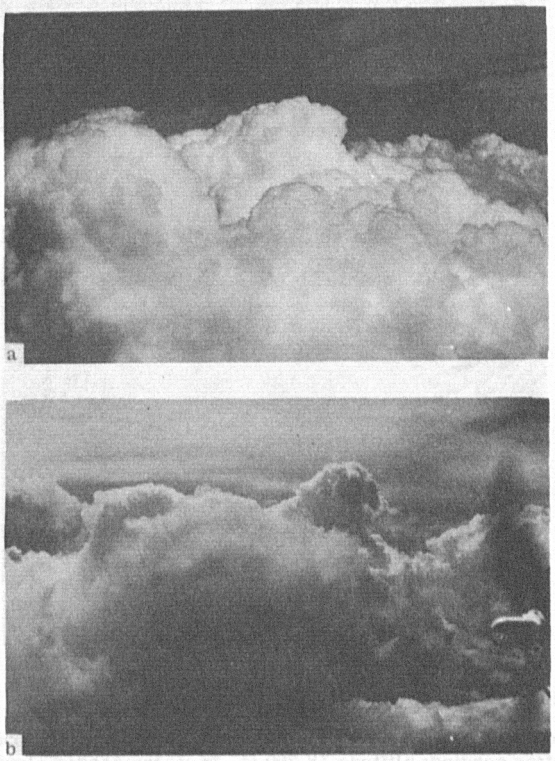


Figure 6.--Second seeded cloud, May 27, 1949.
(a) Before seeding; 1337 CST; altitude 18,200 ft.; direction 035°.
(b) After seeding; 1343 CST; altitude 18,200 ft.; direction 035°.

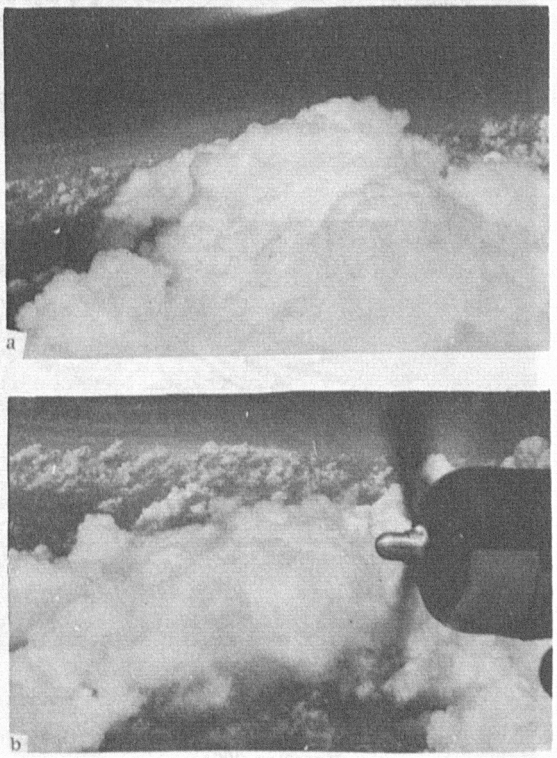


Figure 7.--Third seeded cloud, May 27, 1949.
(a) Before seeding; 1348 CST; altitude 18,200 ft.; direction 105°.
(b) East side dissipating after seeding; 1357 CST; altitude 18,200 ft.; direction 270°.

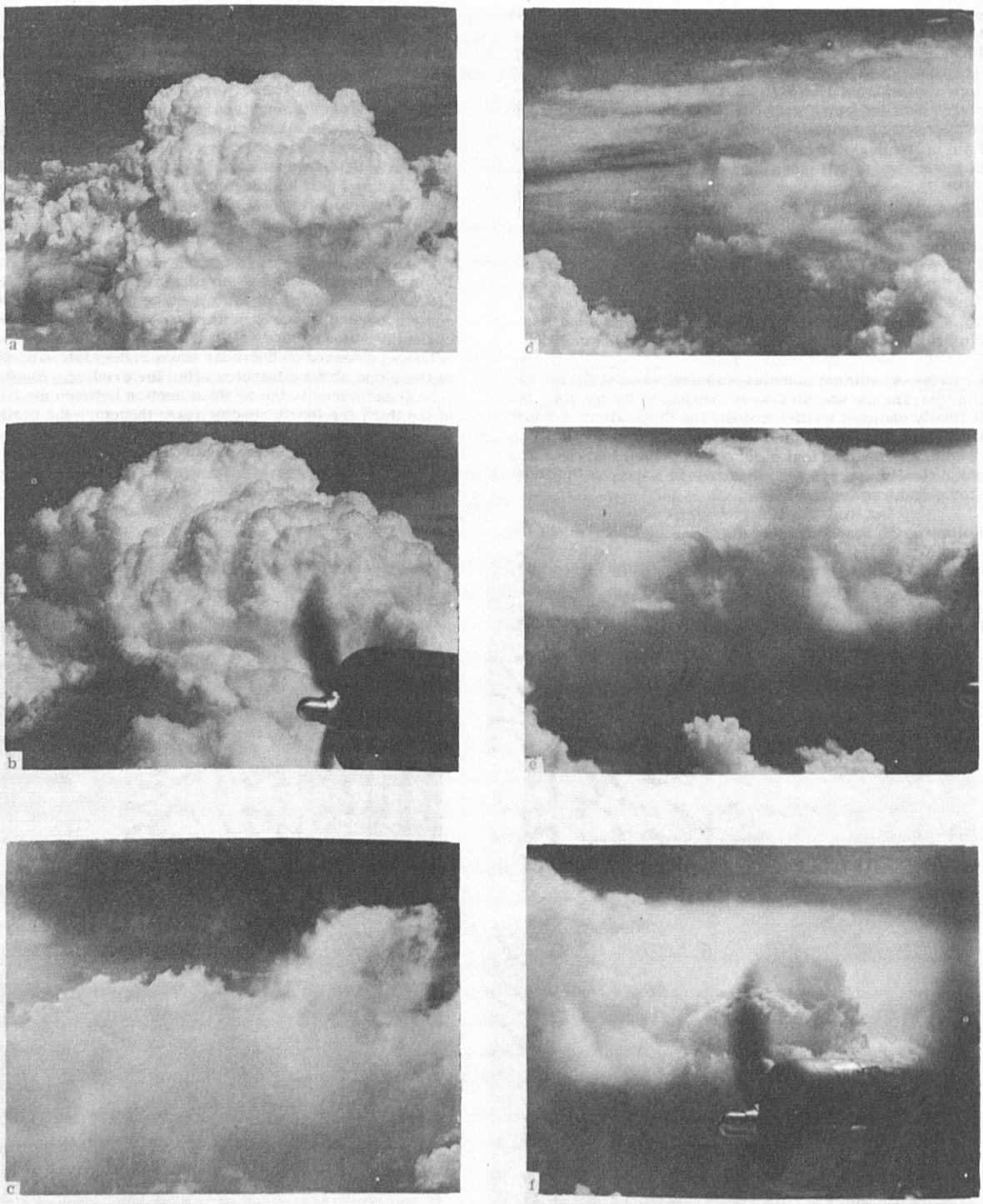


Figure 8.--Fourth seeded cloud, May 27, 1949.

(a) West side before seeding; 1405 CST; altitude 18,200 ft. direction 090°.

(b) After seeding; 1412 CST; altitude 18,200 ft.; direction 090°.

(c) East end dissipating after seeding; 1421 CST; altitude 18,200 ft.; direction 270°.

(d), (e) and (f) Views from east side to west side of cloud after seeding; altitude 18,200 ft. In (f) the seeded cloud is on the left. The large building tower in the center is unseeded.

APS-10 and ground radar scopes.
5th and 6th Seedings: Visual observations (aerial) plus visual observations of the APS-10 and ground radar scopes.

Comments--The seedings were all accomplished very close to thunderstorm clouds. The dissipation of the first cloud may be signfiicant because it was building at the time of seeding. The results of the second seeding are less significant since the cloud was dissipating at the time of the seeding run. The third and fourth seedings were into the same cloud. The third run was from west to east into a towering cumulus. The entire cloud was seeded, but only the eastern end was flown through. Since that portion of the cloud dissipated thereafter, the results may be significant. The western end, however, (even though seeded from above on the third run) continued to build until it was flown through on the fourth seeding run. Following that run, it changed texture and followed the same dissipation cycle as that following the third run into the eastern portion of the cloud. Further significance is added to these two runs since another tower built up immediately west of the fourth seeded area. In the light of the foregoing observations, it is possible that the seeding prevented full growth of the potential storms. While the 5th cloud was observed to be dissipating and changing texture after seeding, other clouds close by were observed to continue building; therefore the seeding results may be significant. The results of the sixth seeding are not altogether significant since the cloud was dissipating at the time of seeding.

The lack of precipitation following the first two seedings is significant since natural showers were developing very close by. The echo that formed and the rain observed after the third and fourth seedings may be significant, but the rain was observed within three minutes after the third seeding - a time much too short to have allowed seeding effects at 18,500 ft. m.s.l. to be observed at 5,000 ft. m.s.l. Another echo formed in the western portion of the cloud before the fourth seeding run into that section and grew to considerable size. It eventually joined with the echo from the eastern part of the cloud. In addition, rime ice as well as clear ice was observed on both the third and fourth seedings; therefore, the cloud probably would have precipitated from natural causes. The seeding may have hastened the natural crystallization process thereby preventing maximum growth of the cloud. Furthermore, other natural echoes were forming within 10 miles of the seeded cloud. The lack of rain after the fifth and sixth seedings is significant since the clouds were considered ideal for seeding - both were supercooled. Natural showers were occurring very close to the seeded clouds. In fact, a natural shower was occurring about 3 miles east of the cloud seeded on the sixth run.

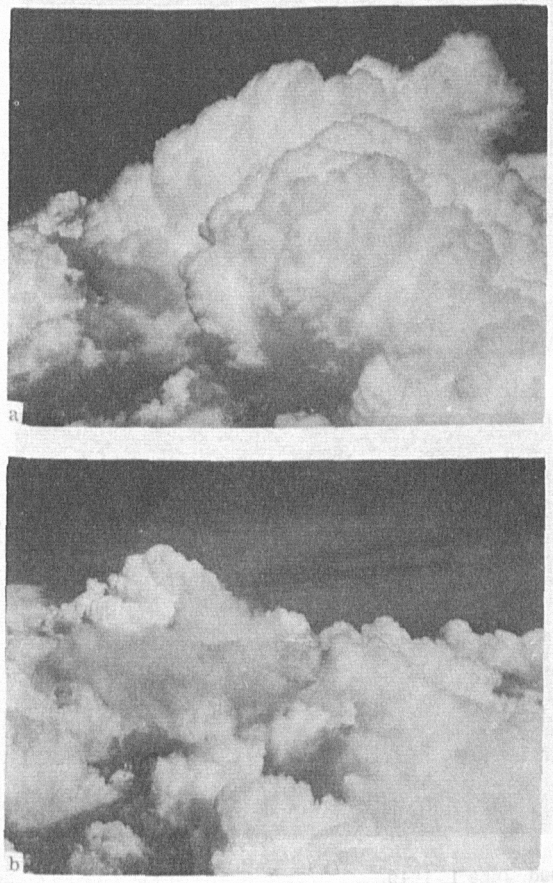


Figure 9.--Fifth seeded cloud, May 27, 1949.
(a) Before seeding; 1440 CST; altitude 18,200 ft.; direction 090°.
(b) After seeding; 1448 CST; altitude 18,200 ft.; direction 120°.

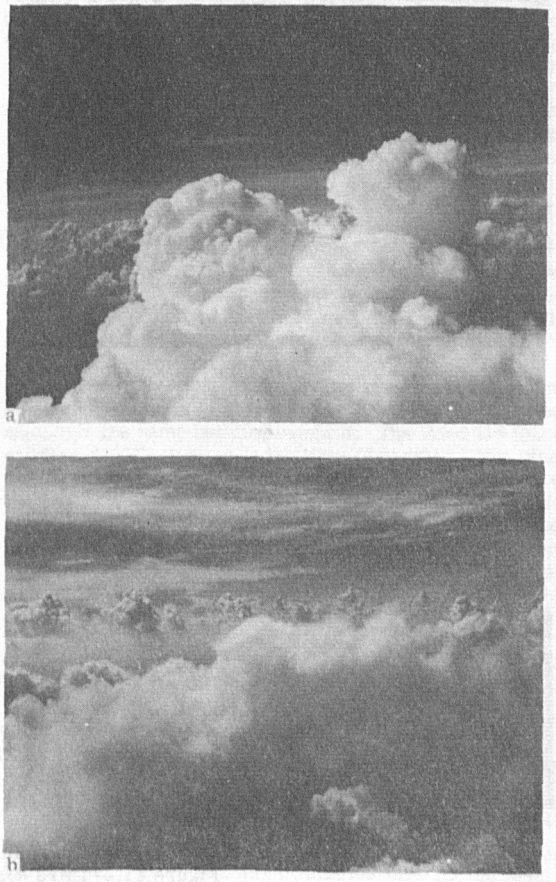


Figure 10.--Sixth seeded cloud, May 27, 1949.
(a) Before seeding; 1455 CST; altitude 18,300 ft.; direction 330°.
(b) After seeding; 1507 CST; altitude 18,300 ft.; direction 330°.

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Cloud Seeding Mission of June 1, 1949

Synoptic Situation--The area of seeding operations was in a cold-frontal zone located in the northern Gulf of Mexico and along the southwestern border of Alabama. A weak low pressure system associated with the cold front was centered off the South Carolina coast.

Conditions of Seeding--Four seeding runs were made, but the second seeded cloud was abandoned immediately after the run because of difficulties in observing the results. The other three runs were made into building cumuli that were giving cloud echoes on the APS-10 radar scope in the seeding aircraft prior to the seeding runs. Rainbows were observed below all seeded clouds - before seeding on the first and fourth runs and immediately after seeding on the third run. All seeded clouds were supercooled and possibly composed of both supercooled water and ice crystals. Light turbulence was also observed in the vicinity of all clouds. The temperatures of the clouds ranged from +21.0° C. near the bases to -6.0° C. near the tops. Bases of the clouds were near 4,000 ft. m.s.l. and the tops ranged from 14,900 ft. to 18,000 ft. m.s.l.

Rate of Seeding--Dry ice pellets were released at the rate of 5 pounds per mile on the first and third runs respectively. An instantaneous drop of 20 pounds of granulated dry ice was released in the center of the cloud on the fourth run.

Time and Duration of Seeding:

1st Seeding: 1411:25 CST; 1 minute plus 25 seconds.
2nd Seeding: Not included.
3rd Seeding: 1427:20 CST; 1 minute plus 50 seconds.
4th Seeding: 1510:38 CST; instantaneous.

Results--The first cloud almost completely dissipated after seeding. Estimates of the amount made by various observers in the seeding aircraft ranged from 90-99 percent. Following the third run the cloud continued to build for about five minutes and then it appeared to shrink with dissipation evident at both the base and top (fig. 11). An ice crystal veil remained above the freezing level. The seeded part of the fourth cloud was estimated to have dissipated about 90 percent soon after the seeding run. The seeded section appeared to have been sheared off from the main body of the large building cumulus leaving a sharp wall

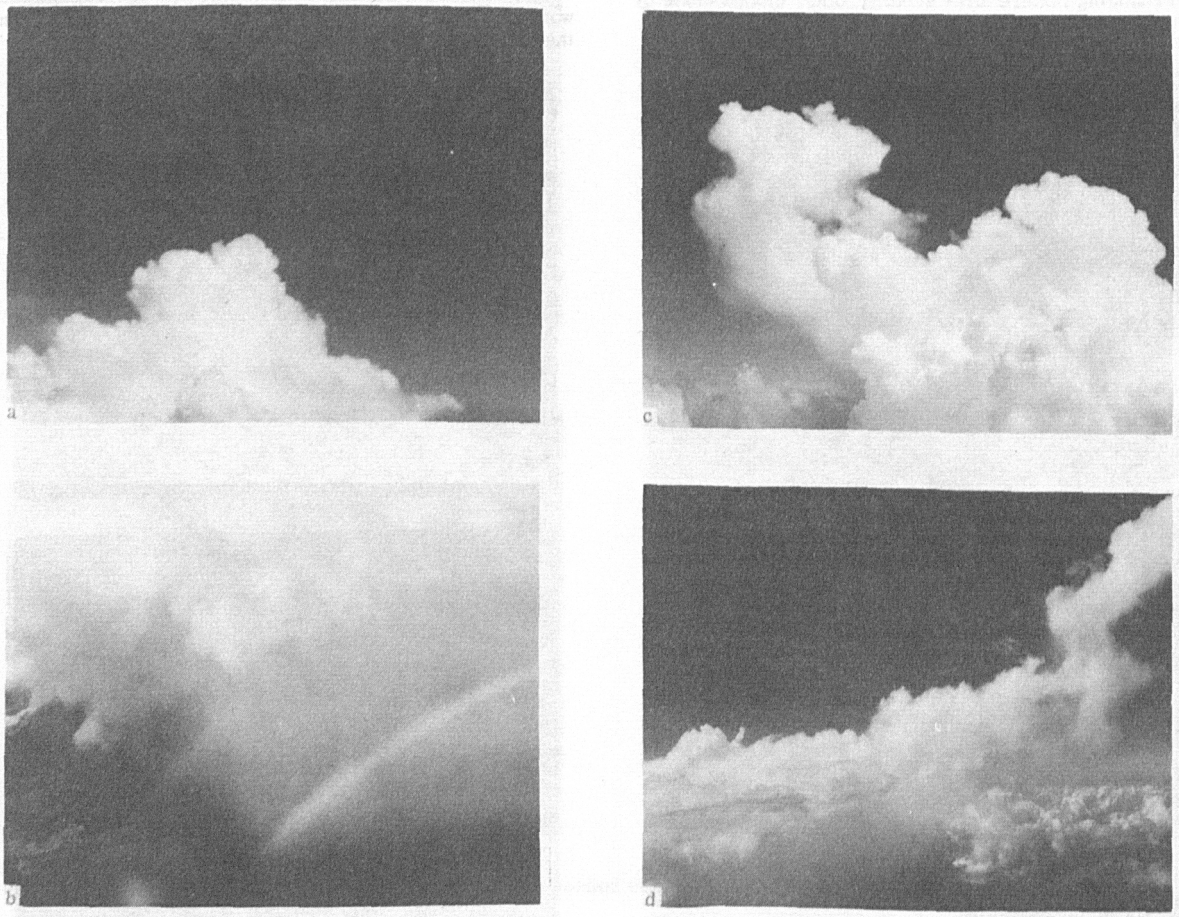


Figure 11.--Third seeded cloud, June 1, 1949.

(a) Before seeding; 1427 CST; altitude 15,000 ft.; direction 110°.
(b) After seeding; 1432 CST; altitude 15,300 ft.; direction 320°. Note rainbow under the cloud.
(c) After seeding; 1437 CST; altitude 15,300 ft.; direction 090°.
(d) After seeding; 1443 CST; altitude 15,300 ft.; direction 270°.

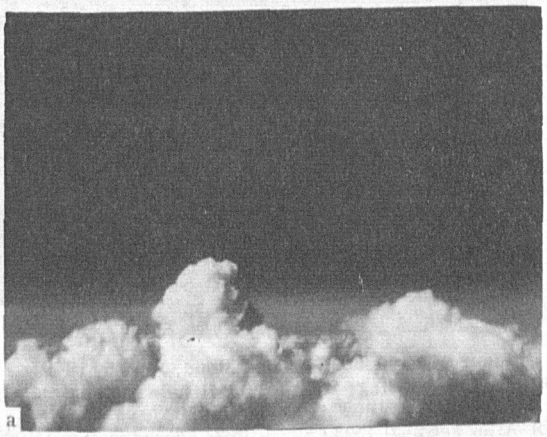
along the seeded side (fig. 12).

Rain was observed from all the seeded clouds, but none of it was believed to be significant.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial) and photographs.
2nd Seeding: Not included.
3rd and 4th Seedings: Visual observations (aerial) and photographs (figs. 11 and 12).

Precipitation:
1st Seeding: Visual observations (aerial) plus visual observations and photographs of the APS-10 and ground radar scopes. (No echo noted on ground radar scope).
2nd Seeding: Not included.
3rd Seeding: Visual observations (aerial) plus visual observations of APS-10 and ground radar scopes.
4th Seeding: Visual observations (aerial) plus visual observations and photographs of the APS-10 and ground radar scopes.



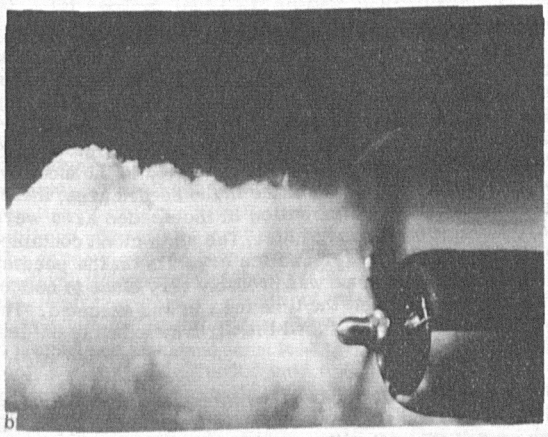


Figure 12.--Fourth seeded cloud, June 1, 1949
(a) Before seeding; 1508 CST; altitude approximately 15,500 ft; direction 020°.
(b) After seeding; 1514 CST; altitude 15,400 ft.; direction 300°. The seeded area is on the right.

Comments--All seeded clouds were building at the time of seeding; therefore the dissipation of the seeded clouds may be significant. However, since all of the clouds were either in the rain stage or just approaching that stage, it is very probable that dissipation would have begun through natural causes in a very short time. Comparing observations of nearby clouds with the seeded ones, however, indicated that the seedings may have hastened the dissipation and prevented maximum growth of the potential storms. After dissipation was observed in the seeded section of the fourth cloud, another cloud about 6 miles to the west was observed to have developed into a much larger and more intense rain area than that of the seeded cloud. In addition, a cloud close to the first seeded cloud passed through the identical stages as the seeded cloud. Following the third seeding, an investigation run was made through the veil portion of the cloud that remained after the seeding run. At that time numerous ice pellets were observed suspended in the air.

Cloud echoes were observed on the APS-10 radar scope in the seeding aircraft from all seeded clouds prior to the seeding runs, but no echo was observed by the ground radar observer from the first cloud. The appearance of the other echoes on the ground radar scope lagged slightly behind their appearance on the APS-10 radar scope. Rainbows were observed prior to the seeding runs on the first and third runs, however, which indicated rain was actually falling prior to the dry ice release. Rain was not encountered by observers in the low observation plane under the third cloud until about one minute after seeding. Since the cloud was giving a radar return prior to the seeding and the time required for rain formed as a result of seeding to fall from the base of the cloud would have been longer than the actual time interval observed, it is unlikely that the seeding was instrumental in initiating the rain. Natural showers were observed within 30 miles of all seeded clouds.

Cloud Seeding Mission of June 5, 1949

Synoptic Situation--The area of seeding operations was located on the southeast side of a weak high pressure system centered at 1230 CST in northwest Missouri. The isobaric pattern indicated light offshore circulation.

Conditions of Seeding--Six seeding runs were made into supercooled cumulus clouds. The first and second runs were into the same building cumulus. The third and fourth clouds were dissipating at the time of seeding. The other clouds were building and they, in addition to the portion of the first cloud seeded on the second run, contained ice crystals as well as supercooled water prior to the seeding runs. Turbulence was encountered in all clouds flown through. The temperatures ranged from +16.0° C. at the bases near 5,600 ft. m.s.l. to -6.0° C. near the tops which ranged from 15,000-18,000 ft. m.s.l.

Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on the 1st, 2nd, 5th, and 6th runs and 4 pounds per mile on the 3rd and 4th runs.

Time and Duration of Seeding:

1st Seeding: 1442:50 CST; 1 minute plus 0 seconds.
2nd Seeding: 1455:45 CST; 1 minute plus 25 seconds.
3rd Seeding: 1514:10 CST; 1 minute plus 5 seconds.
4th Seeding: 1525:15 CST; 0 minutes plus 25 seconds.
5th Seeding: 1536:35 CST; 0 minutes plus 35 seconds.
6th Seeding: 1550:40 CST; 1 minute plus 0 seconds.

Results--The first seeding resulted in the dissipation of the seeded pinnacle (fig. 13). The second seeding into

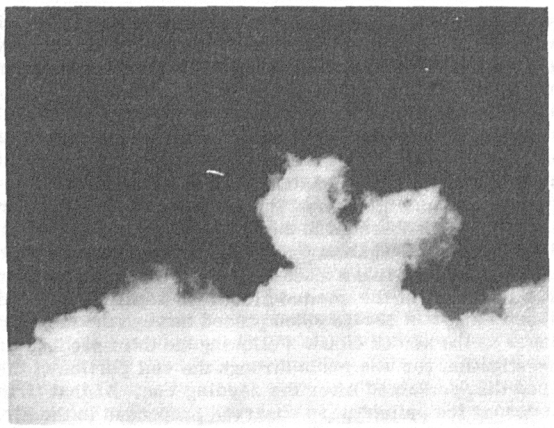


Figure 13.--First seeded cloud, June 5, 1949. After seeding; 1445 CST; altitude approximately 15,000 ft.; direction 340°.

another tower of the same cloud resulted in more dissipation than the first run. The top of the cloud dissipated and the base broke up leaving a stratiform cloud (fig. 14). The next two seedings resulted in rapid dissipation, but the clouds were dissipating at the time of seeding. Some dissipation was noted after the 5th seeding, but the observations were indefinite because the whole cloud began to dissipate - even portions that were not seeded. The sixth seeding resulted in dissipation of the top in the seeded area (fig. 15).

The low observation plane was not used on the first two runs. No radar echo, however, was observed after the first seeding; therefore it is believed that no rain fell. After the second seeding, a small faint echo was observed on the radar scope and a rainbow was observed below the cloud. No rain or radar echoes were noted in the third and fourth seeded areas before or after seeding. The rain that probably fell after the fifth seeding run is not significant since a moderate size echo was observed from the cloud before seeding (fig. 16). Light rain and a radar echo were observed in the sixth seeded area about eleven minutes after seeding.

Method of Verification:

Structural:

1st, 2nd and 6th Seedings: Visual observations (aerial) and photographs (figs. 13, 14 and 15).

3rd, 4th and 5th Seedings: Visual observations (aerial).

Precipitation:

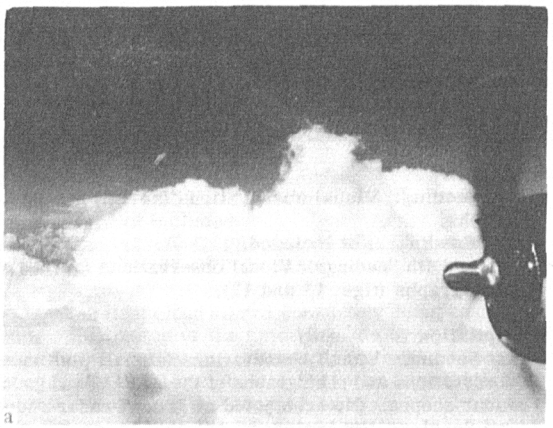
1st and 2nd Seedings: Visual observations (aerial) plus visual observations of APS-10 as well as visual observations and photographs of ground radar scope.

3rd and 4th Seedings: Visual observations (aerial) plus visual observations and photographs of APS-10 and ground radar scopes.

5th Seeding: Visual observations (aerial) plus visual and photographs of APS-10 and ground radar scopes (fig. 16).

5th Seeding: Visual observations (aerial) and visual observations of APS-10 radar scope.

Comments--The first and second runs were made into the same cloud. Dissipation was observed after both seedings, and the final result was a stratiform cloud. The dissipation



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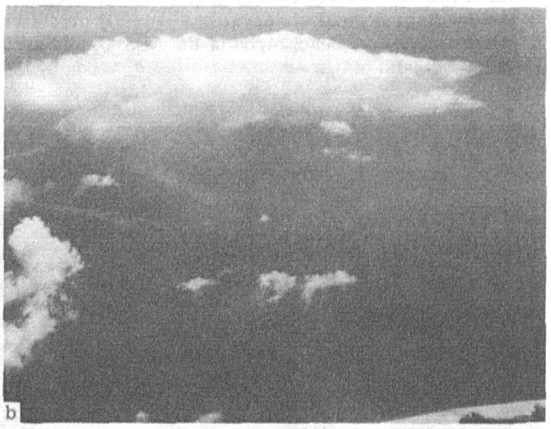
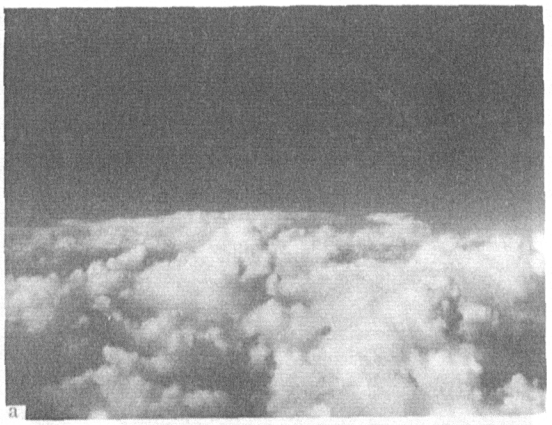


b

Figure 14.--Second seeded cloud, June 5, 1949.
(a) Before seeding; 1452 CST; altitude approximately 15,000 ft.; direction 300°.
(b) After seeding; 1503 CST; altitude approximately 15,000 ft.; direction 040°. Note the rainbow under the cloud.

may be significant since the cloud was building slightly and was composed of supercooled water. The third and fourth seedings were into naturally dissipating clouds. Comparative observations, however, with neighboring clouds indicated that the dissipation may have been accelerated as a result of seeding. The fifth run was into a large cloud mass, but natural dissipation started in the unseeded portion about the time it started in the seeded area; therefore the results of dissipation in the seeded area were partly obscured and indefinite. The sixth cloud contained both supercooled water and ice crystals on the seeding run; therefore the cloud was probably very close to noticeable crystallization at the time the run was executed. The seeding may have hastened the already existing natural processes.

No precipitation or radar echoes were observed after the first, third, and fourth runs. A faint echo did appear in the seeded area after the second seeding which was made in another portion of the cloud seeded on the first run. At the same time, however, another echo formed in a cloud 3-4 miles from the second seeded portion about 4 minutes before the seeded echo appeared. Some ice as well as supercooled water was observed on the seeding run; there-



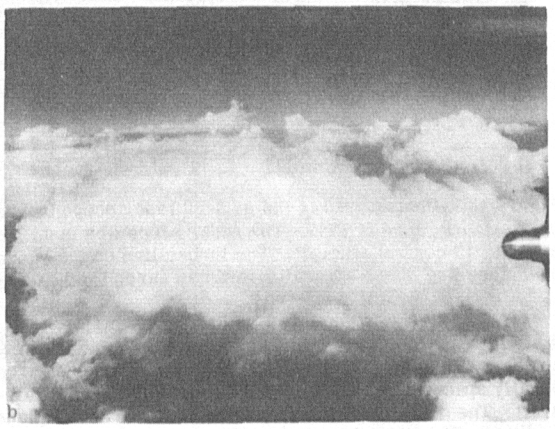


Figure 15.--Sixth seeded cloud, June 5, 1949.
(a) Before seeding; 1547 CST; altitude approximately 17,000 ft.; direction 020°.
(b) After seeding; 1604 CST; altitude approximately 17,000 ft.; direction 360°.

fore the cloud probably would have shown an echo without seeding. The significant point here, however, is that the echo from the unseeded cloud grew to a much larger size than the seeded echo. Such observations indicate the seeding may have prevented full growth of the cloud. Since the echo was so small and faint, it is doubtful that the rain that resulted reached the ground. The fifth seeding was into the southern edge of an already existing cloud echo (fig. 16). The entire cloud and echo were observed to dissipate after seeding. No extension of the echo into the seeded area was observed; therefore all results of the run must have been primarily from natural causes. The sixth run was made into a cloud that contained some ice crystals as well as supercooled water. The seeded part dissipated, but another tower was observed to build on one side of the cloud. A dry run was made into the tower and it soon followed the same process leaving the cloud in a stratiform condition. An echo did not appear on the APS-10 in the seeding aircraft until after the dry run. After the appearance of the echo, a rainbow was observed below the cloud and observers in the low observation plane reported the rain light and reaching the ground. It was also observed that the rain was about the same intensity as that occurring naturally within 5 miles. In the light of these observations, it is doubtful

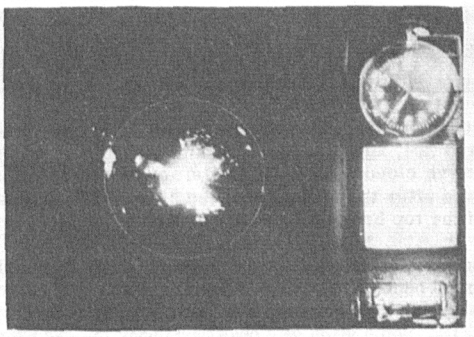


Figure 16.--Photograph of the ground radar scope 35 seconds before fifth seeding, June 5, 1949. The ground radar scope was installed in the B-17 control aircraft. The lubber line indicates the true heading of the aircraft, 273°. To the upper left of the scope center, the three equally spaced dots indicate the position of the seeding aircraft. Immediately below the aircraft position, the small dot and the large elongated area indicate cloud echoes from the cloud to be seeded. Although the cloud echo is indicated in two parts, visual observations at the time of seeding definitely substantiated that the southern edge of a large cloud was seeded; therefore the two echoes were probably from the same cloud - just different portions thereof. The photograph definitely indicates that a pre-existing cloud echo was seeded; therefore any rain observed after seeding was insignificant. The data available here verifies that the cloud was passing into the natural crystallization stage before it was treated with dry ice.

that the seeding had too much effect on the rain reported. The seeding may have hastened the dissipation of the cloud top, but observations after the dry run indicated that some of the dissipation observed in the seeded area may have been due to the effect of the aircraft since it was flown through the cloud on the seeding run.

Cloud Seeding Mission of June 6, 1949

Synoptic Situation--The area of seeding operations at 1230 CST was in a weak north to south flow of air on the southwest edge of a low pressure system centered in eastern Canada. No frontal systems affected the area throughout the mission but scattered showers were reported in western Florida and throughout the operations area during the mission.

Conditions of Seeding--Three building cumulus clouds were seeded. The first and third runs were very near already existing thundershower activity but the second run was far enough from natural shower activity that it was not directly influenced by such activity. The second run, however, was not under radar control. Most of the clouds in the area were observed to build through the freezing level, change to ice crystals and then dissipate naturally. Icing and light turbulence was encountered in all clouds flown through. In addition, some snow was observed in the top of the first cloud. The bases of the clouds were near 5,000 ft. m.s.l. with temperatures of +18.0° C. The tops ranged from 17,000 ft. to 20,000 ft. m.s.l. and temperatures varied from -5.0° to -10.0° C.

Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on the first and third runs and 4 pounds per mile on the second run.

Time and Duration of Seeding:

1st Seeding: 1356:10 CST; 0 minutes plus 50 seconds.

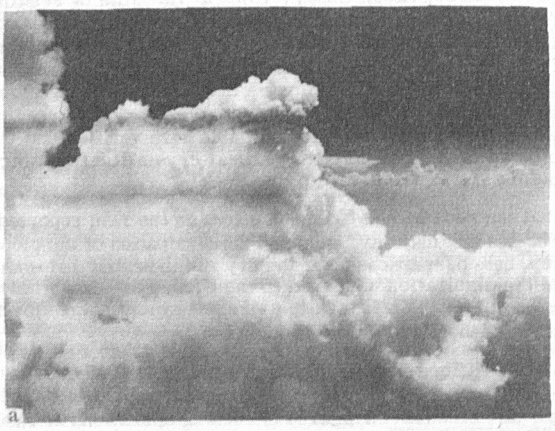
2nd Seeding: 1433:43 CST; 0 minutes plus 37 seconds.
3rd Seeding: 1518:35 CST; 0 minutes plus 38 seconds.

Results--The tower seeded on the first run dissipated but it was impossible to determine the total amount of dissipation (fig. 17). Following the second and third runs (figs. 19 and 20), about 50 percent and 90 percent of the respective clouds dissipated. Before dissipation was observed after the second run, the cloud built up some and then the top broke off and dissipated.

Precipitation after the first seeding was difficult to determine because the north side of an existing thunderstorm was seeded and the cloud was precipitating before seeding (fig. 18). Some virga was observed under the second seeded cloud, but a short time later another tower built up and produced the same results naturally. A small amount of precipitation and a rainbow were observed under the third cloud also.

Method of Verification:

Structural:
1st, 2nd and 3rd Seedings: Visual observations (aerial) and photographs (figs. 17, 19 and 20).



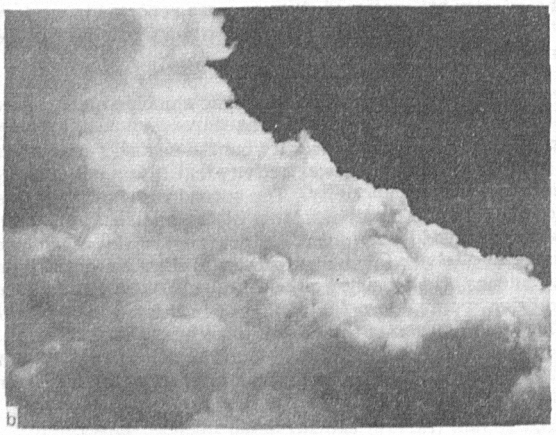


Figure 17.--First seeded cloud, June 6, 1949.
(a) Before seeding; 1355 CST; altitude 18,500 ft.; direction 210°.
(b) After seeding; 1401 CST; altitude 18,500 ft.; direction 210°.

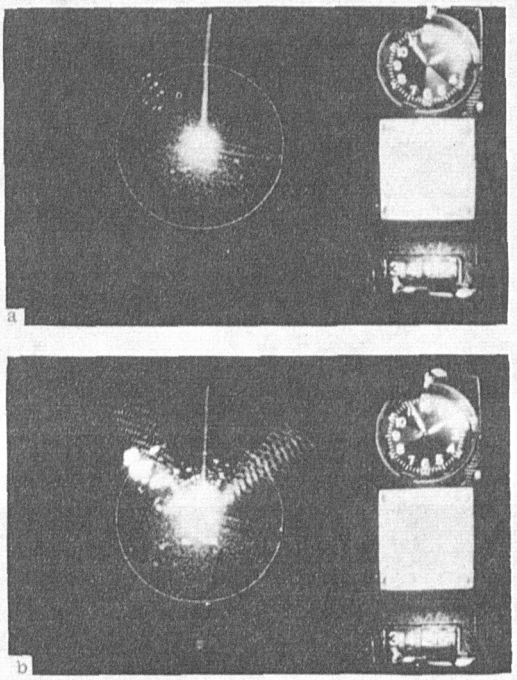


Figure 18.--Photographs of the APS-20 radar scope before first seeding, June 6, 1949. The radar scope was installed in tne B-17 control aircraft. The lubber line on the scope is the heading of the aircraft. In these cases the heading was 273° true heading.

(a) Scope photograph one minute and 45 seconds before seeding. To the upper left of the scope center, the three equally spaced dots indicate the location of the seeding aircraft. The dot nearest the scope center is the actual plane position. The other three unequally spaced dots indicate the position of the low observation plane.
(b) A video picture immediately before seeding. The large area to the upper left of the picture is the echo from part of the cloud to be seeded. A combination of both photographs clearly indicates the conditions of the area before seeding. The seeding, as indicated by the photographs, was into the northwest side of the cloud which was already precipitating at seeding time. This was verified not only by these pictures but also by visual observations from the low observation plane which was definitely under the existing echo. The two cloud pictures in figure 17 also substantiate the radar observations. Note in both cloud pictures the large towering portion of the cloud to the left of photographs. The headings on which the pictures were taken verify that the left hand portion of the cloud was the part giving the radar return before seeding.

Precipitation:
1st Seeding: Aerial observations (visual) plus visual observations and photographs of APS-10 and ground radar scopes (fig. 18).
2nd Seeding: Visual observations (aerial).
3rd Seeding: Visual observations (aerial) plus visual observations and photographs of APS-10 and ground radar scopes.

Comments--The first and third seedings were very close to an already existing thunderstorm. In fact, the first seeding was made into a tower on the northwest edge of the storm. Following this run, the top of the cloud dissipated. This may be significant since the cloud was building at the time of seeding, but observations here were incomplete and

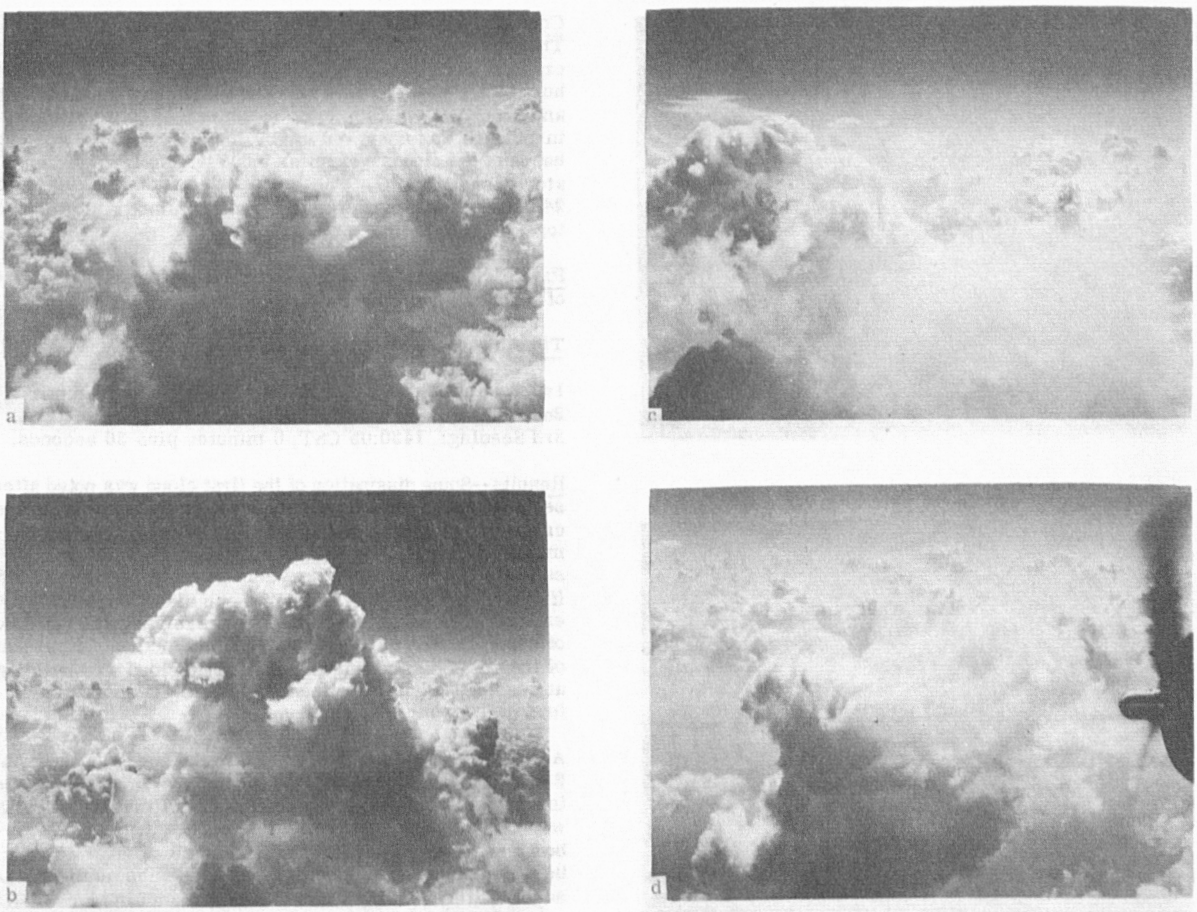


Figure 19.--Second seeded cloud, June 6, 1949.

(a) Before seeding; 1435 CST; altitude 18,000 ft.; direction 270°.
(b) After seeding; 1438 CST; altitude 18,000 ft.; direction 270°.
(c) After seeding; 1444 CST; altitude 18,000 ft.; direction 270°.
(d) After seeding; 1450 CST; altitude 18,000 ft:; direction 270°.

confused. The cloud top was near the level at which natural dissipation was occurring in neighboring clouds, but since some texture change was observed immediately after seeding it is possible that the seeding hastened the dissipation.

A small extension of the already existing cloud echo was observed in the seeded area a short time after seeding. It's size, however, in proportion to the primary echo was very small and insignificant.

Following the second seeding, the cloud continued to build for a short time and then the top broke off and dissipated. Further observations revealed that another tower was generated a short time later and went through the same process naturally. Such observations detract from the significance of the seeding results.

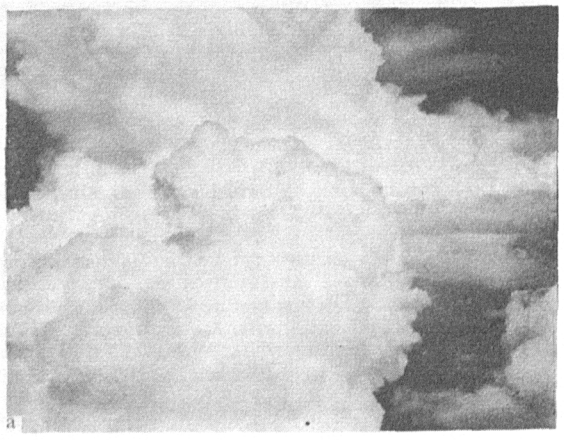
Light rain was observed after seeding on the second run, but an equivalent amount was also observed under the newly generated tower in the same area. In other words, the results of seeding were no different from those observed naturally in the same area.

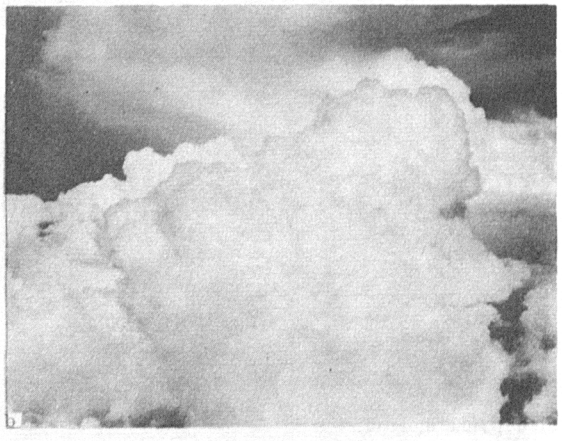
The third seeding was accomplished about 6 miles southwest of a thunderstorm. The top of the cloud dissipated after seeding. The dissipation was much more rapid than the natural dissipation close by. In order to make a test run through the dissipating top after seeding, the pilot had to dive the aircraft about 2,000 ft.

Some light rain and a rainbow were observed under the seeded cloud after seeding, but no echo was observed from the cloud. An echo return appeared immediately west of the seeded cloud during observation of the seeding results. Observers in the low observation plane confused the rain from that cloud with the seeded cloud results, but radar observations from the seeding aircraft verified that the measurable precipitation reported by the observers underneath was from an unseeded cloud close by.

Cloud Seeding Mission of June 7, 1949

Synoptic Situation--The area of seeding operations at 1230 CST was located in a very weak and indefinite pressure field. All frontal areas were far enough removed from the operations area that they did not have an influence on the results observed. However, the surface winds indicated a weak convergence zone through southern Mississippi and Alabama.





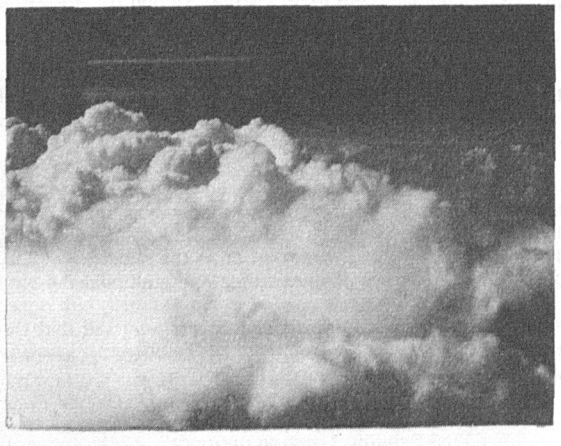


Figure 20.--Third seeded cloud, June 6, 1949.
(a) Before seeding; 1519 CST; altitude 17,000 ft.; direction 245°.
(b) After seeding; 1522 CST; altitude 17,000 ft.; direction 090°
(c) After seeding; 1526 CST; altitude 17,000 ft.; direction 360°.

Conditions of Seeding--Three cumulus clouds were seeded. The first two clouds were dissipating and contained ice crystals at the time of seeding. Some supercooled water, however, was also present. The third cloud was building and contained only supercooled water. Light to moderate turbulence was observed in all clouds flown through. The bases of the clouds were near 5,000 ft. m.s.l. with temperatures of +17.0° C. The tops varied from 22,000 ft. to 24,000 ft. m.s.l. with temperatures in the vicinity of the tops ranging from -16.0° to -25.0° C.

Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on all seeding runs.

Time and Duration of Seeding:

1st Seeding: 1351:12 CST; 0 minutes plus 18 seconds.
2nd Seeding: 1410:12 CST; 0 minutes plus 27 seconds.
3rd Seeding: 1430:05 CST; 0 minutes plus 38 seconds.

Results--Some dissipation of the first cloud was noted after seeding, but the cloud was observed to be changing to ice crystals and dissipating at the time of seeding. Approximately 50 percent of the cloud dissipated. Following the second seeding about 90 percent of the cloud dissipated (fig. 21), but probably not all of the dissipation was due entirely to seeding. The cloud was dissipating at the time of seeding. The third seeding resulted in about 75 percent of the cloud dissipating (fig. 22). The cloud was building at seeding time and continued to build for a short time before dissipation was observed.

A small cloud echo was observed in the seeded area about 8-10 minutes after the first seeding and virga was observed to fall from the cloud, but it is doubtful that the results were entirely the aftermath of seeding. Virga and a rainbow were observed under the second cloud after seeding. but the cloud was showing a faint cloud echo on the radar scope in the seeding aircraft before seeding. A small amount of virga was observed below the cloud after seeding on the third run, and a small cloud echo formed on the radar scope in the seeded area.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial) and photographs.
2nd and 3rd Seedings: Visual observations (aerial) and photographs (figs. 21 and 22).

Precipitation:
1st Seeding: Visual observations (aerial) plus photographs of ground radar scope and visual observations of APS-10 radar scope.
2nd Seeding: Visual observations (aerial) plus visual observations of APS-10 radar scope in seeding aircraft.
3rd Seeding: Visual observations (aerial) plus visual observations and photographs of APS-10 radar scope in seeding aircraft.

Comments--Dissipation was observed in all clouds seeded. The total amount of dissipation of the first two clouds may not be entirely significant. The clouds contained some ice crystals and were dissipating naturally before seeding. Comparative observations with neighboring clouds, however, indicated the seeded clouds dissipated much more rapidly than neighboring clouds. The third cloud contained only supercooled water; therefore the observers were confident that the texture change and dissipation observed were the result of seeding. Their observations also revealed, however, that other clouds were dissipating in a

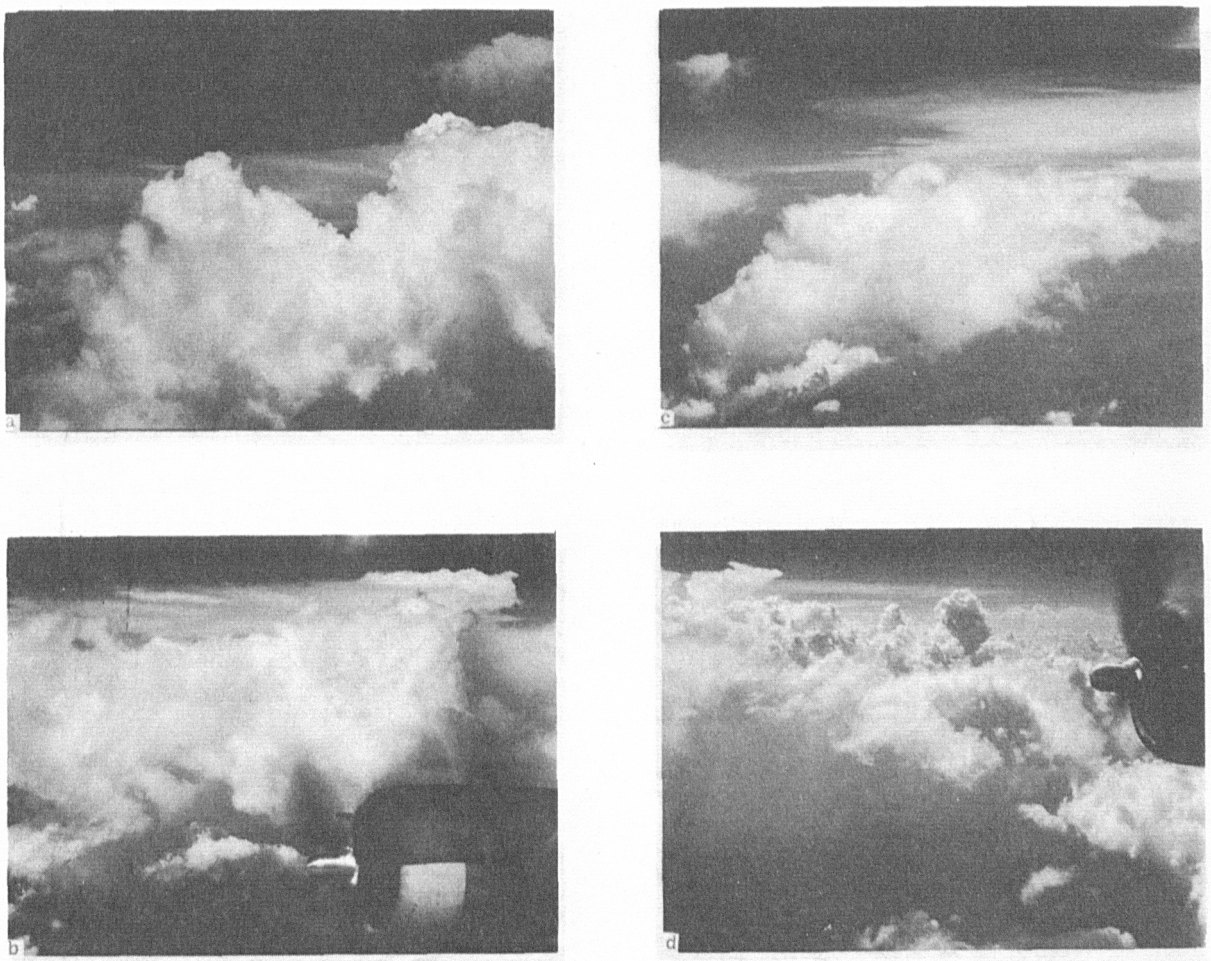


Figure 21.--Second seeded cloud, June 7, 1949

(a) Before seeding; 1410 CST; altitude 20,000 ft.; direction 080°.
(b) After seeding; 1415 CST; altitude 20,000 ft.; direction 080°.
(c) After seeding; 1416 CST; altitude 20,000 ft.; direction 150°.
(d) After seeding; 1421 CST; altitude 20,000 ft.; direction 280°.

similar manner; but they concluded that the natural dissipation was at a much slower rate than that observed in the seeded cloud.

Small radar echoes were observed from all seeded clouds - after seeding on the first and third runs and before seeding on the second run. The echo before seeding on the second run was very faint and was noted through visual observations of the scope. Virga was also observed below all seeded clouds; and in addition, a rainbow was observed under the second cloud. Since the first two clouds contained some ice crystals at the time of seeding, some light precipitation probably would have fallen from those clouds through natural causes. The seeding, however, may have hastened the occurrence of the noticeable crystallization. The results of the third seeding are far more significant since no ice crystals were present before seeding. A run through the dissipating portion of the third cloud after seeding indicated the presence of ice crystals and snow. The amount of rain that fell, however, was very insignificant and did not reach the ground. In contrast, natural showers of greater intensity were present within 3-6 miles of all seeded areas.

Cloud Seeding Mission of June 8, 1949

Synoptic Situation--The seeded area at 1230 CST was located in a very weak pressure field south of a cold front oriented west-northwest to east-southeast through Alabama. At 1430 CST scattered showers and thunderstorms were occurring over eastern Alabama and western Florida.

Conditions of Seeding--Three seeding runs were made. The first two clouds were building at the time of seeding, but the third one was in the dissipation stage. Ice crystals and supercooled water were observed in the first cloud along with heavy turbulence. The second cloud contained only supercooled water. The third seeding run was made over the top of the cloud, but since a change in texture was observed after seeding, the cloud must have contained supercooled water. The bases of the clouds were near 3,500 ft. m.s.l. with temperatures near +21.0° C. The tops ranged from 19,000 ft. to 25,000 ft. m.s.l. with temperatures near the tops varying from -10.0° to -25.0° C.

Rate of Seeding--Dry ice pellets were released at the rate of 5 pounds per mile on all seeding runs.

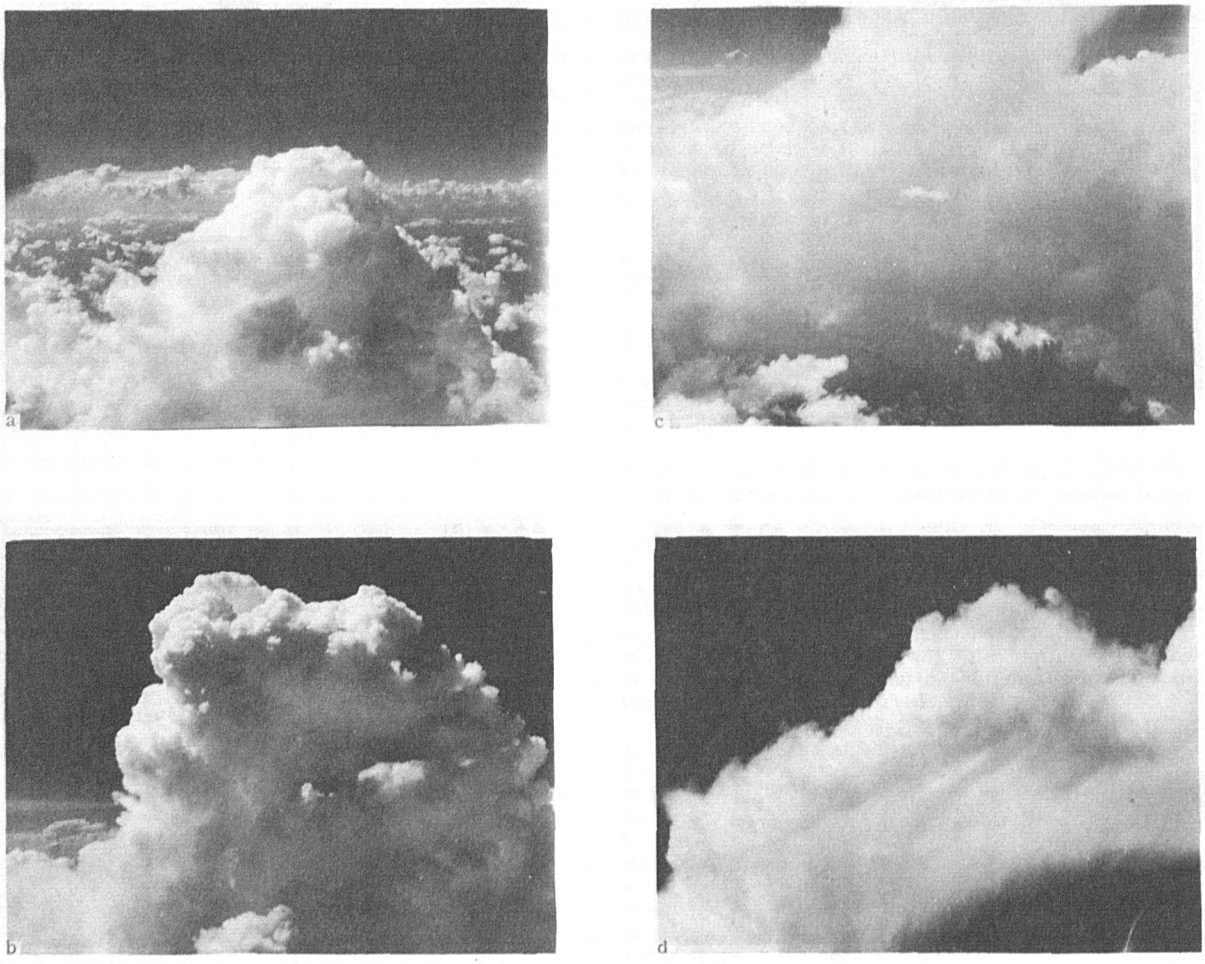


Figure 22.--Third seeded cloud, June 7, 1949

(a) Before seeding; 1430 CST; altitude 20,000 ft.; direction 360°.
(b) After seeding; 1435 CST; altitude 20,000 ft.; direction 360°.
(c) After seeding; 1444 CST; altitude 21,000 ft.; direction 360°.
(d) After seeding; 1445 CST; altitude 21,000 ft.; direction 360°.

Time and Duration of Seeding:

1st Seeding: 1439:40 CST; 1 minute plus 7 seconds.
2nd Seeding: 1512:30 CST; 0 minutes plus 25 seconds.
3rd Seeding: 1533:45 CST; 1 minute plus 20 seconds.

Results--Observations of the first cloud after seeding were very indefinite (fig. 23). The cloud was building at the time of seeding and during the 10 minutes of observation, some dissipation was observed. It was impossible to estimate the amount because the cloud became confused with neighboring shower clouds. Following the second seeding, about 75 percent of the cloud dissipated (fig. 24). After the third run about 50 percent of the cloud was observed to dissipate (fig. 25).

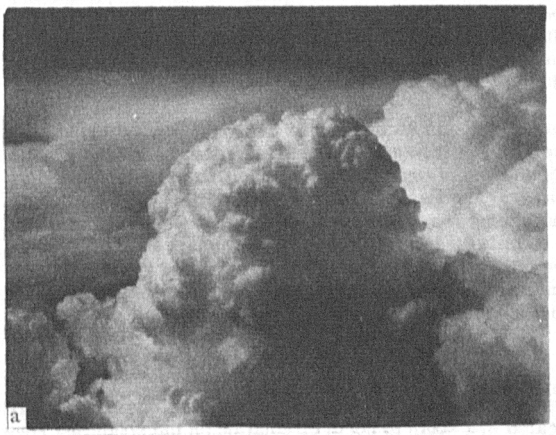
Precipitation results after the first run are not too significant because the cloud was believed to be producing rain at the time of seeding. Some light virga fell from the second cloud after seeding, but no precipitation was observed to fall from the third cloud either before or after it was treated.

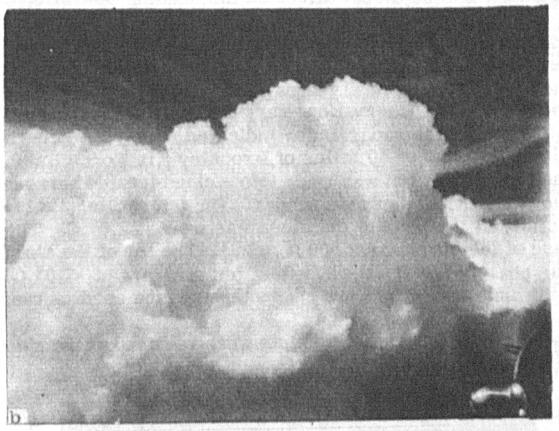
Method of Verification:

Structural:
1st, 2nd and 3rd Seedings: Visual observations (aerial) and photographs (figs. 23, 24, 25).

Precipitation:
1st, 2nd and 3rd Seedings: Visual observations (aerial).

Comments--This mission was conducted without radar control or the low observation plane. The first cloud, however, contained both supercooled water and ice crystals. Heavy turbulence was also encountered and visual observations indicated that the cloud was probably producing a significant shower at the time it was seeded. The seeding may have prevented maximum growth of the cloud but observations were so difficult that the cloud was abandoned after 10 minutes without arriving at definite conclusions as to the results observed. The second and third clouds contained only supercooled water; therefore their dissipation is more significant. The third cloud, however, was in the natural dissipation stage before seeding; therefore of all three





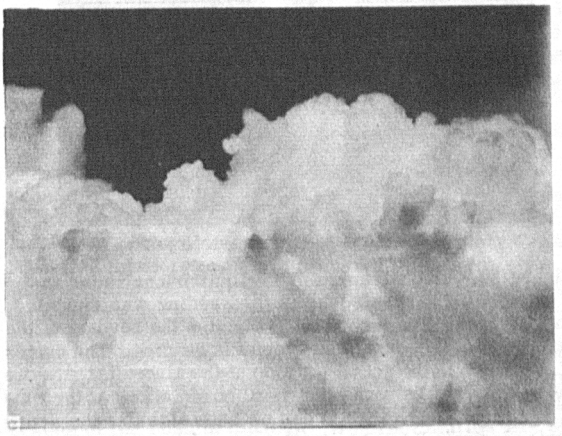
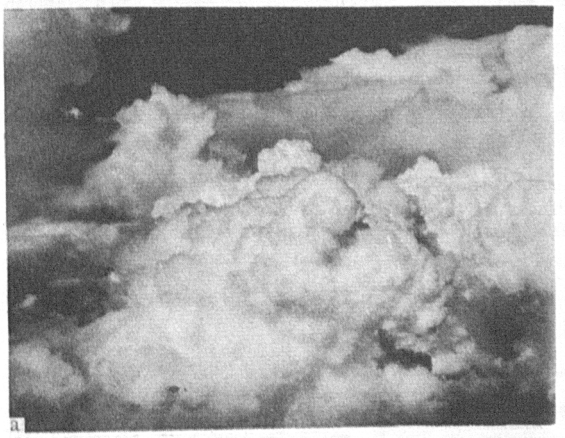
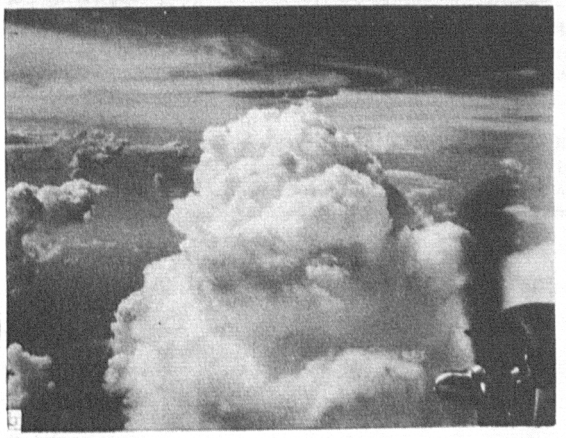


Figure 23.--First seeded cloud, June 8, 1949.
(a) Before seeding; 1439 CST; altitude 20,500 ft.; direction 345°.
(b) After seeding; 1446 CST; altitude 20,500 ft.; direction 030°.
(c) After seeding; 1450 CST; altitude 20,500 ft.; direction 100°.





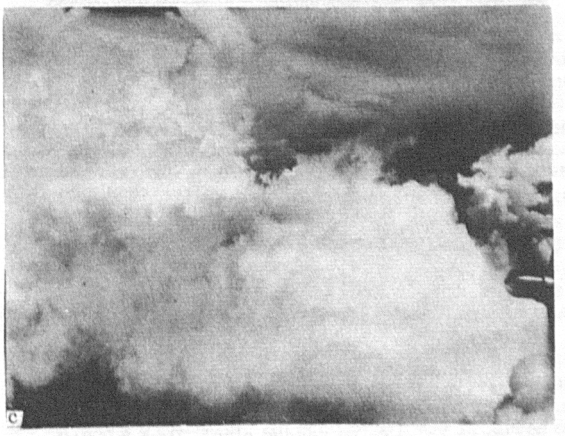
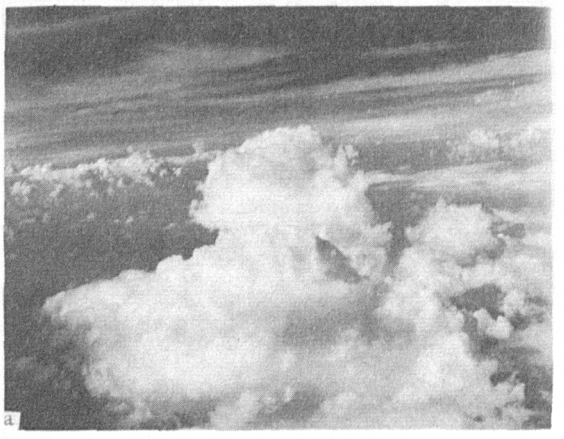
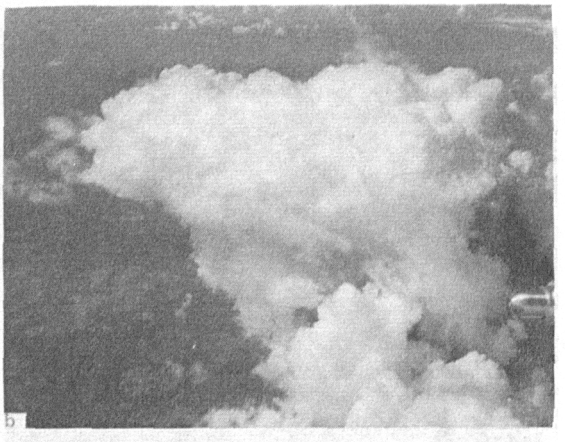


Figure 24.--Second seeded cloud, June 8, 1949.
(a) Before seeding; 1512 CST; altitude 21,000 ft.; direction 060°.
(b) After seeding; 1516 CST; altitude 21,000 ft.; direction 330°.
(c) After seeding; 1520 CST; altitude 21,000 ft.; direction 140°.





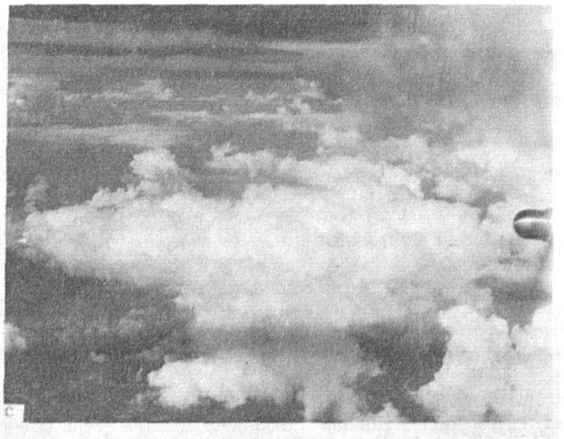


Figure 25.--Third seeded cloud, June 8, 1949.
(a) Before seeding; 1533 CST; altitude 21,000 ft.; direction 360°.
(b) After seeding; 1541 CST; altitude 21,000 ft.; direction 360°.
(c) After seeding; 1542 CST; altitude 21,000 ft.; direction 060°.

seedings, the second one is by far the most meaningful. After dissipation in the second seeded area, a new tower built up alongside the dissipated area - an observation that added further significance to that particular run.

Some light rain was observed below the second cloud after seeding, but it was not believed that it reached the ground. The amount of precipitation that fell from the seeded cloud was very inconsequential when compared with the amounts and intensities of natural showers that were falling within 6-10 miles. In the light of these observations, it would seem that the seeding prevented maximum growth of a potential rain area. No precipitation was observed after the third seeding run.

Cloud Seeding Mission of June 9, 1949

Synoptic Situation--The area of seeding operations was located in a south to north circulation on the southwest edge of a large anticyclone centered over the eastern portion of the Great Lakes. A weak frontal system was located north and east of the seeding area, but it was far enough removed so that it had no direct affect on the seeding operations.

Conditions of Seeding--One seeding run was made into a building cumulus. Observations were indefinite because of the proximity of several thunderstorms. The chaotic cloud condition made observations very difficult. At the time of the mission, the radar scope indicated numerous echoes within a radius of 60 miles of Brookley Air Force Base, and the seeding run was made into a cloud located between two pronounced elongated echoes. The temperature in the vicinity of the base of the cloud was near +22.0° C. The base of the cloud was 2,500 ft. m.s.l. The top of the cloud was near 17,900 ft. m.s.l. with a temperature of -7.0° C. Icing and turbulence were encountered on the seeding run.

Rate of Seeding--Dry ice pellets were released at the rate of 5 pounds per mile.

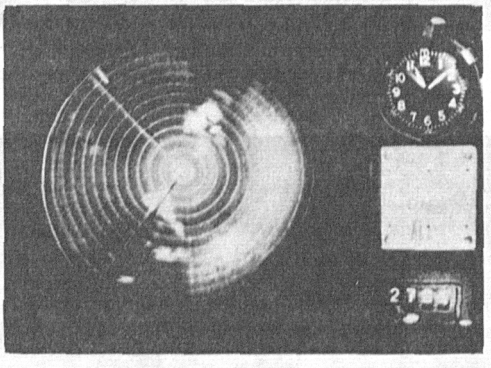


Figure 26.--Photograph of APS-10 airborne radar in the B-17 seeding aircraft just as the seeding was executed, June 9, 1949. The lubber line indicates the heading of the aircraft - in this case, 200° compass heading. The center of the scope is the actual position of the aircraft; therefore the scope pictures verify the visual observations at the time of seeding. The large areas on both sides of the scope center indicate the large thunderstorms that were observed visually at the time of seeding. The area eventually became so hazzardous because of the thunderstorm conditions that the observers were forced to abandon the cloud, but this photograph and subsequent photographs give a clear and accurate picture of conditions before, during, and after seeding.

Time and Duration of Seeding:

1st Seeding: 1108:38 CST; 0 minutes plus 40 seconds.

Results--Some texture change was observed and about 10 percent of the seeded cloud dissipated.

Rain was reported by observers in the low observation plane after seeding, but it was not believed to be entirely the result of seeding.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial).

Precipitation:
1st Seeding: Visual observations (aerial) plus visual observations and photographs of APS-10 and APS-20 radar scopes (fig. 26).

Comments--The dissipation observed may be significant since the cloud was building at the time of seeding, but the fact that the seeding was not able completely to overcome possible resistant forces created by the thunderstorms on both sides of the seeded cloud is far more significant.

Precipitation and cloud-to-ground lightning were observed from the storm clouds on both sides of the seeded area before the seeding run. A cloud echo, appeared in the seeded area just as the aircraft came out of the cloud on the seeding run. The low observation plane was flown under the area and observers reported rain falling between the two storms after seeding, but radar photographs indicated that a similar natural echo formed very close to the seeded portion about the same time; therefore some of the rain observed may have been from natural causes. The two previously mentioned thunderstorms were observed to be merging during the time of observation of the seeded area. In fact, such a dangerous storm area developed, the observers were forced to abandon the area. In the light of the above observations, it was concluded that the results after seeding were not entirely the aftermath of seeding. Further changes involving unification of the cloud area and part of the subsequent new rain areas, therefore, were probably the result of both natural and seeding influences. The only definitely significant observation that could be made on this mission was the change in texture observed; therefore it may be concluded that the seeding may have hastened to completion what would have happened naturally had the cloud been left untreated.

Cloud Seeding Mission of June 10, 1949

Synoptic Situation--The area of seeding operations was located in a weak south to north circulation on the western side of an anticyclone centered off the Virginia Coast. Scattered thunderstorms had occurred in the area prior to 1230 CST and other storms were still in progress northeast of Mobile, Ala., at that time.

Conditions of Seeding--Two building cumulus clouds were seeded about 20 miles northwest of New Orleans, La. The presence of a higher overcast made observations and photographs of the results difficult. No precipitation was observed to fall from the upper deck during the time of the mission. All clouds that were seeded were attacked before their tops reached the upper overcast. The first cloud was composed of both supercooled water and ice crystals and was giving a radar return at the time of the seeding run. The second seeding run was made over the top of the cloud, therefore it could not be definitely determined whether ice crystals were present prior to seeding. At any rate the cloud was not giving a radar return; consequently it was assumed that the cloud was composed of supercooled water. Light turbulence was encountered in the cloud flown through. The bases of the clouds were near 1,500 ft. m.s.l. and the tops ranged from 17,500 ft. to 20,000 ft. m.s.l. Temperatures ranged from +25.0° C. at the bases to -9.0° C. near the tops.

Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on the first run and 4 pounds per mile on the second run.

Time and Duration of Seeding:

1st Seeding: 1136:40 CST; 1 minute plus 25 seconds.
2nd Seeding: 1156:13 CST; 0 minutes plus 32 seconds.

Results--Following the first run, the cloud split vertically into two parts along the seeded line. It was estimated that about 50 percent of the cloud dissipated. Following the seeding run, the portion of the cloud that was not seeded built an estimated 1,000 ft. The second seeding followed the usual cycle that had been observed several times previously. After the seeding, the cloud split horizontally into two parts with only veils of ice crystals remaining above the seeding level (fig. 27). The lower portion of the cloud still remained intact.

Precipitation was observed from both seeded clouds. The first cloud, however, was giving a radar return prior to the seeding run. A low observation plane was not used, but observers in the seeding aircraft did not believe that the rain from the second cloud reached the ground.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial).
2nd Seeding: Visual observations (aerial) and photographs (fig. 27).

Precipitation:
1st and 2nd Seedings: Visual observations (aerial) plus visual observations and photographs of radar scope in seeding aircraft.

Comments--The dissipation of the clouds after seeding may be significant since the clouds were building at the time of seeding. The first cloud, however, already contained ice crystals as well as supercooled water; therefore the seeding probably hastened the crystallization process and subsequent dissipation of the seeded portion. It was also observed that the seeding did not affect the whole cloud. A portion of the cloud that was not seeded continued to build. The second seeding is significant since the seeding resulted in a change in texture and dissipation of the top. It was not definitely determined whether the cloud was supercooled before seeding, but the occurrence of the texture change indicated that supercooled water was present.

The precipitation that fell after the first seeding lacks significance since a rainbow, cloud echo, and ice crystals were observed on the seeding run. The results of the second run are far more meaningful. An echo return was observed on the APS-10 radar scope soon after seeding and virga was observed to fall from the base. Since this cloud was not indicating a radar return prior to seeding, it is possible that the seeding effected the small amount of virga that fell from the cloud. The fact, however, that natural showers of greater intensity were occurring close by indicates that the seeding may have prevented full growth of the seeded cloud.

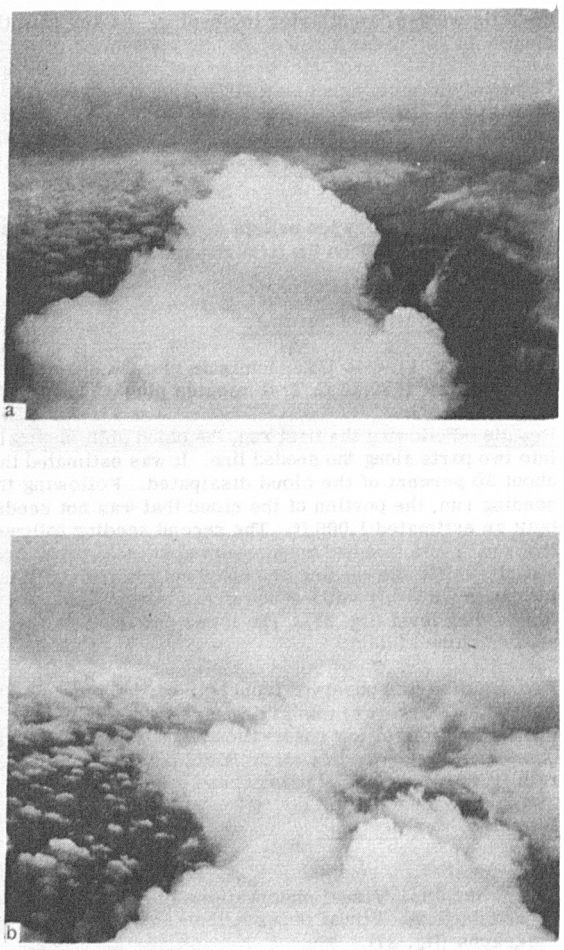


Figure 27.--Second seeded cloud, June 10, 1949.
(a) Before seeding; 1156 CST; altitude 18,000 ft.; direction 150°.
(b) After seeding; time and direction unknown, altitude approximately 17,500 ft.

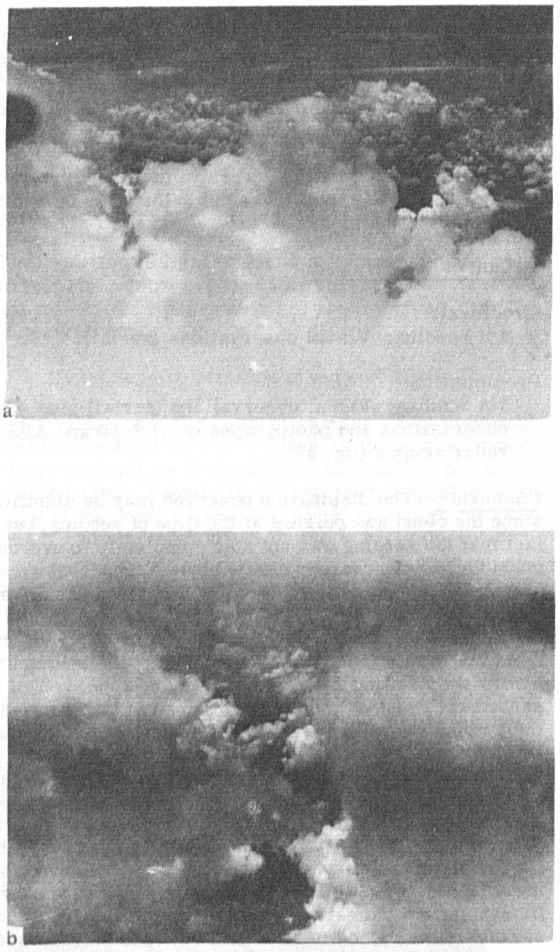


Figure 28.--Second seeded cloud, June 13, 1949.
(a) Before seeding; 1140 CST; altitude 19,000 ft.; direction 220°.
(b) After seeding; 1147 CST; altitude 19,000 ft.; direction 250°. Note: Seeded cloud is on right, unseeded cloud on left.

Cloud Seeding Mission of June 13, 1949

Synoptic Situation--The seeding area at 1230 CST was located in a moderate south to north circulation. The only frontal system was located considerably northwest of the area of operations. At 1230 CST the front was located in southeastern Oklahoma thence across the southern portion of the Texas Panhandle. A squall line preceded the frontal system and was located through central Arkansas. The squall line was very slow moving, however, and did not move into the operations area during seeding nor during the 24 hours following seeding.

Conditions of Seeding--Two building cumulus clouds were seeded. The cumuli in the vicinity of the seeded clouds were observed to build to 18,000-19,000 ft. m.s.l. change to ice crystals, and then dissipate through natural causes. The clouds that were flown through contained ice crystals and supercooled water. Light to moderate turbulence was also encountered. The bases of the clouds were near 2,500 ft. m.s.l. with temperatures near +22.0° C. The tops ranged from 18,000 ft. to 19,500 ft. m.s.l. with temperatures in the vicinity of the tops -6.0° and -8.0° C. respectively on the two seeding runs.

Rate of Seeding--Dry ice pellets were dropped at the rate of 5 pounds per mile on both seeding runs.

Time and Duration of Seeding:

1st Seeding: 1118:36 CST; 0 minutes plus 47 seconds.
2nd Seeding: 1141:38 CST; 1 minute plus 10 seconds.

Results--On the first run, one of two clouds very close together was seeded. The seeded cloud changed texture and about 50 percent of it dissipated after seeding. A short time later another section of the cloud built to 18,500 ft. m.s.l. and then dissipated in the same manner as the seeded portion had done.

Following the second seeding, about 50 percent of the cloud dissipated (fig. 28). The dissipation observed here was very similar to that observed after the first seeding and also that observed in other clouds in the immediate vicinity.

The low observation plane was not able to locate the seeded clouds accurately, but observers in the seeding aircraft observed rainbows under both clouds after seeding. The rain,

however, was not believed to have reached the ground.

Method of Verification:

Structural:
1st Seeding: Visual observations (aerial) and photographs.
2nd Seeding: Visual observations (aerial) and photographs (fig. 28).

Precipitation:
1st and 2nd Seedings: Visual observations (aerial) plus visual observations and photographs of the APS-10 and ground radar scopes.

Comments--The actual composition of the first cloud was not determined because the seeding drop was made from above the cloud top; however, a texture change was observed after seeding; therefore some supercooled water must have been present. Dissipation of the seeded area was very similar to subsequent natural dissipation of another section of the seeded cloud; therefore the seeded cloud, if it had been left untreated, probably would have dissipated of its own accord. The seeding may have hastened its dissipation slightly. It should be noted that the top of the cloud was almost at the level at which natural dissipation was taking place in neighboring clouds; therefore the dissipation, if hastened by seeding, was started only a short time before possible natural processes would have accomplished the same result.

Although not definitely determined, it was believed that the cloud was not precipitating at the time of seeding. The subsequent rainbow and rain, therefore, may have been seeding results. In any event, the amount that fell must have been very light and probably did not reach the ground since a radar echo from the cloud was never noted either on the radar scope in the seeding aircraft or on the ground radar scope. Natural showers were forming within 5-10 miles of all seeded clouds throughout the entire mission.

The dissipation and sequence of events after the second seeding paralleled that of the first seeding very closely; therefore the same conclusions in regard to precipitation and dissipation may be made. One major observation was made here, however, that was not obtainable on the first run. The seeded cloud definitely contained ice crystals as well as supercooled water prior to the seeding run. This fact further substantiates the assumption that the cloud was very close to crystallization at the time of the seeding run and the seeding only slightly hastened the natural processes to completion.

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(b) R. D. Coons, R. C. Gentry, Ross Gunn, "First Partial Report on the Artificial Production of Precipitation - Stratiform Clouds, Ohio," U. S. Weather Bureau Research Paper No. 30, August 1948.

2. (a) R. D. Coons, E. L. Jones, Ross Gunn, "Second Partial Report on the Artificial Production of Precipitation - Cumuliform Clouds, Ohio 1948," Bulletin of the American Meteorological Society, vol. 29, No. 10, December 1948, pp. 544-546.
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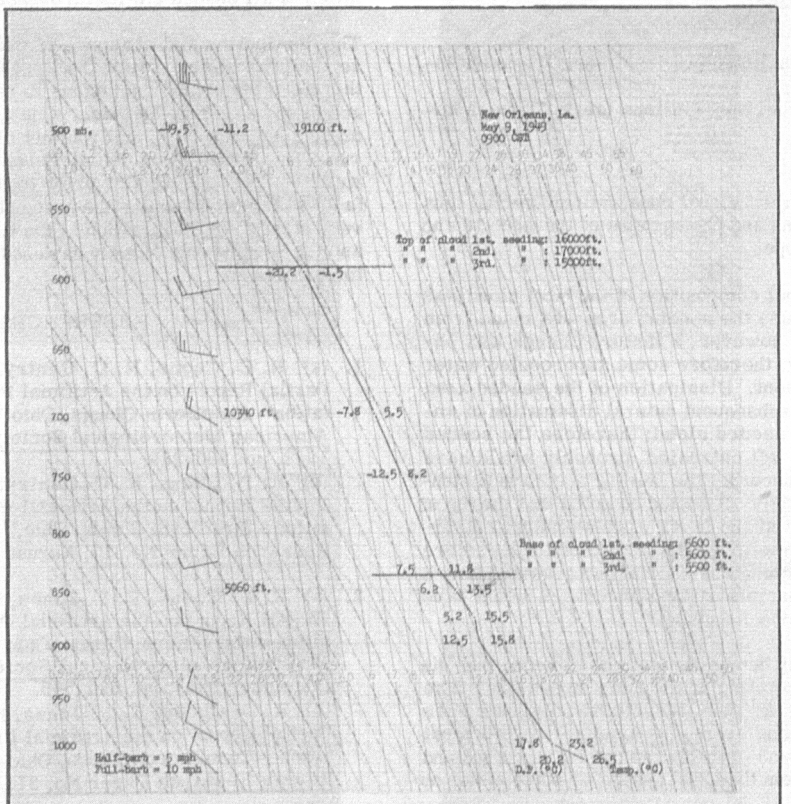
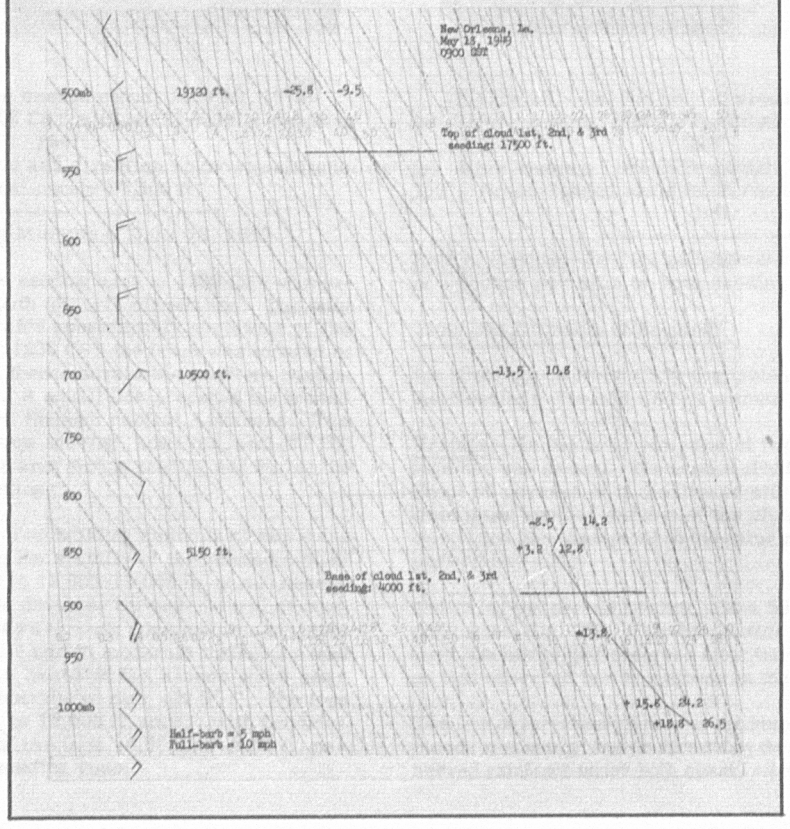
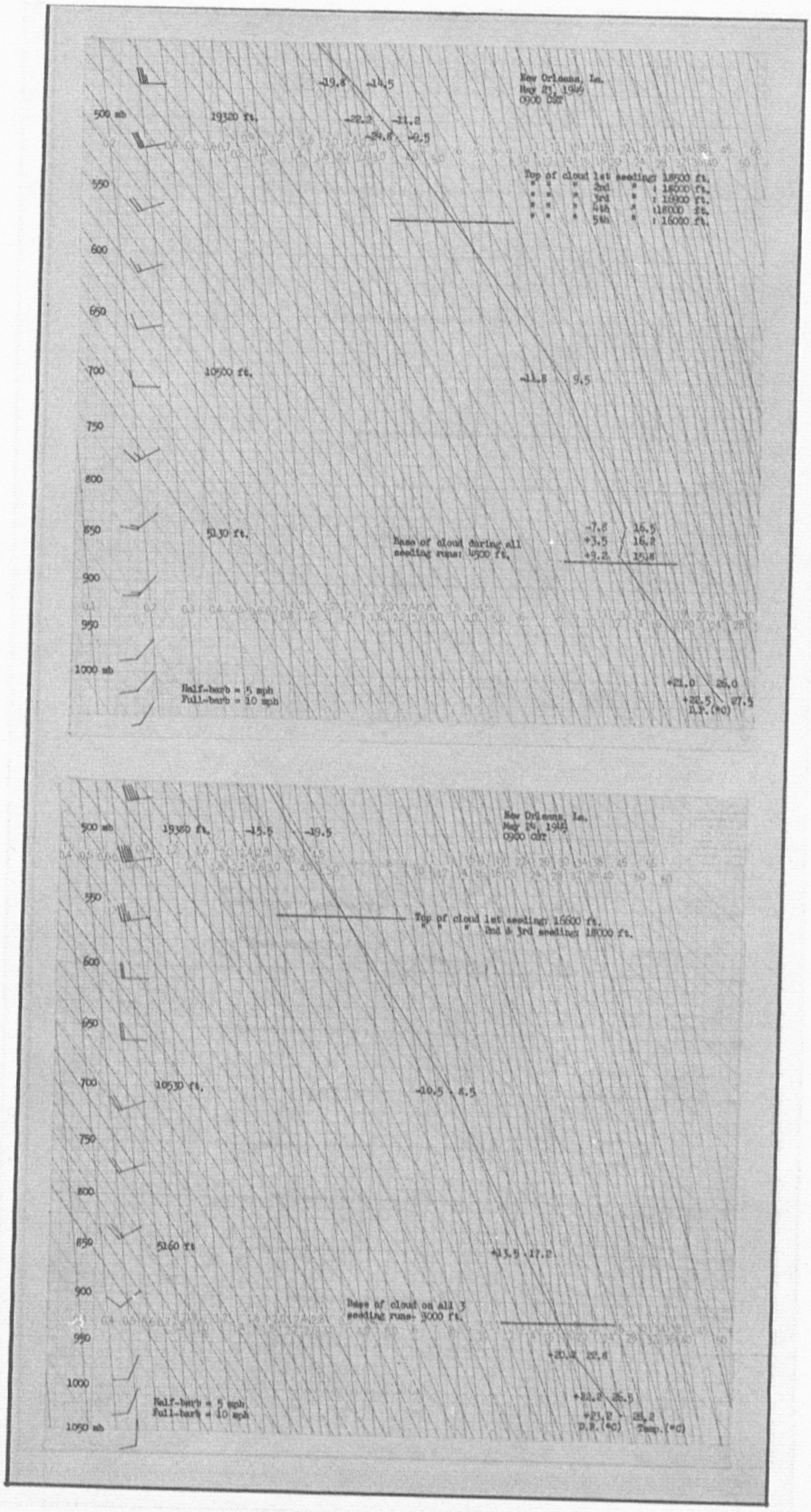
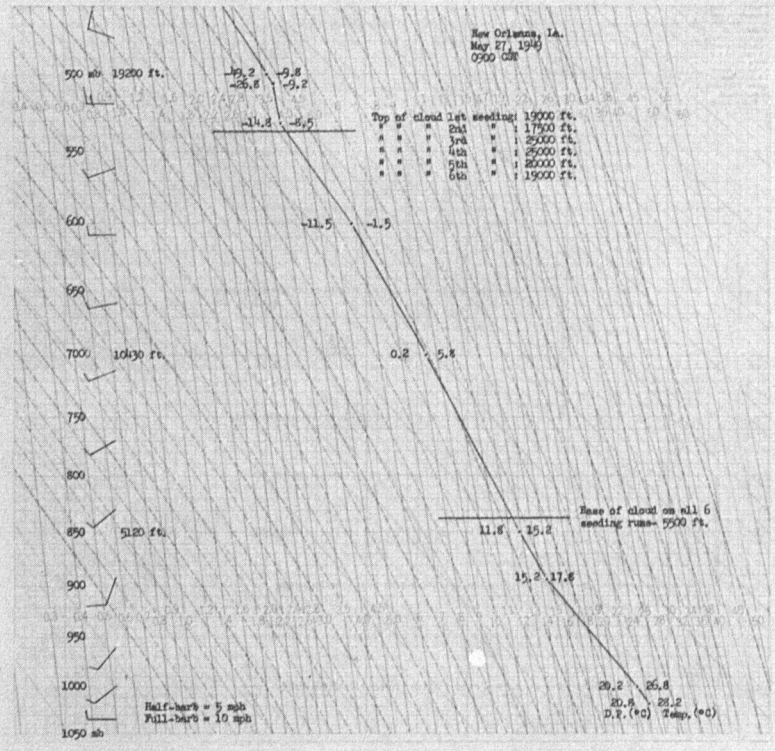
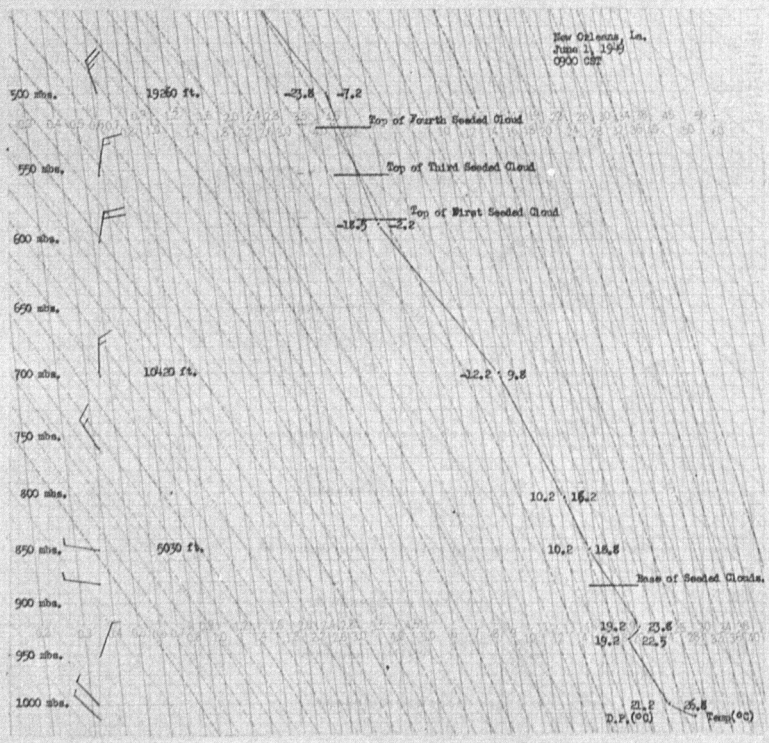
ATMOSPHERIC SOUNDINGS

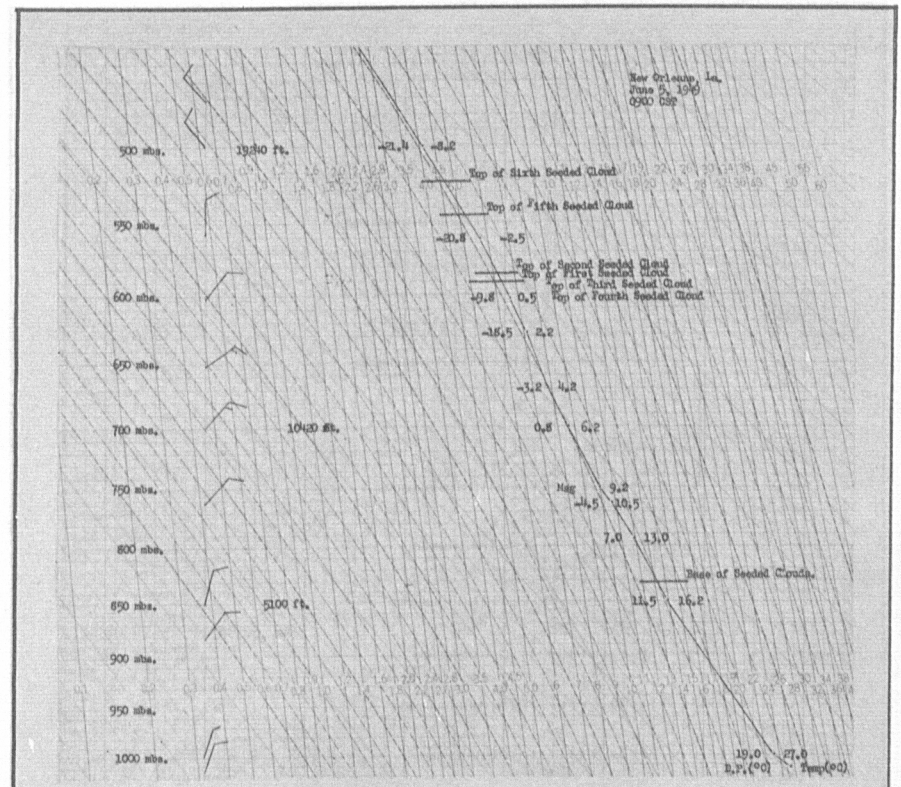


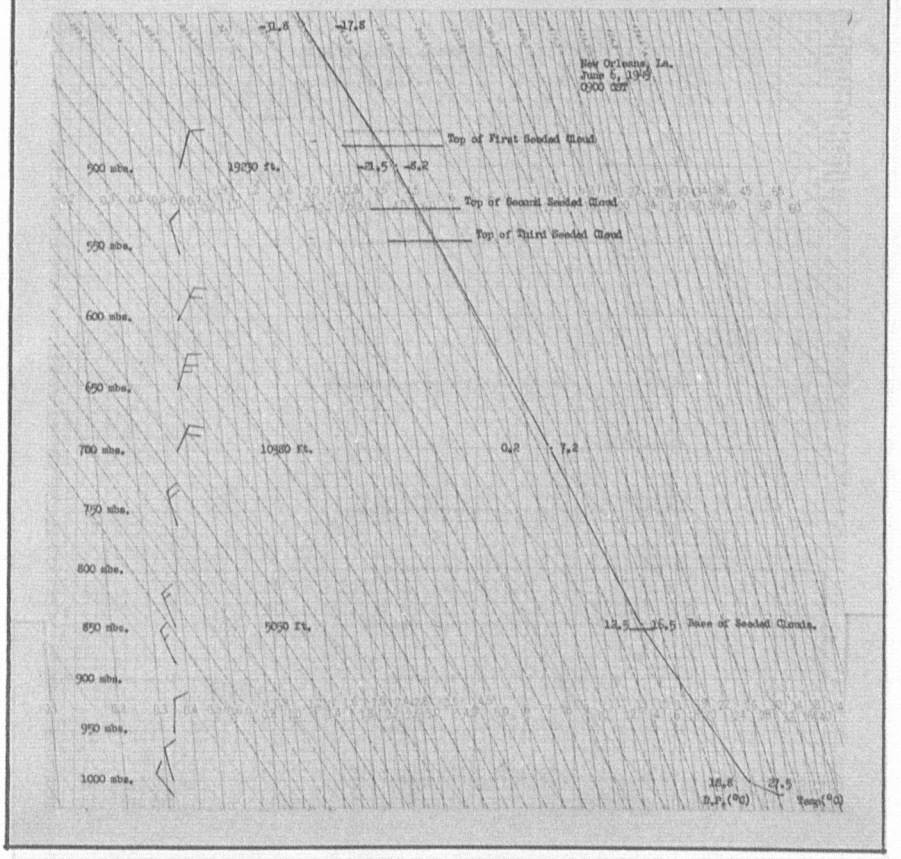


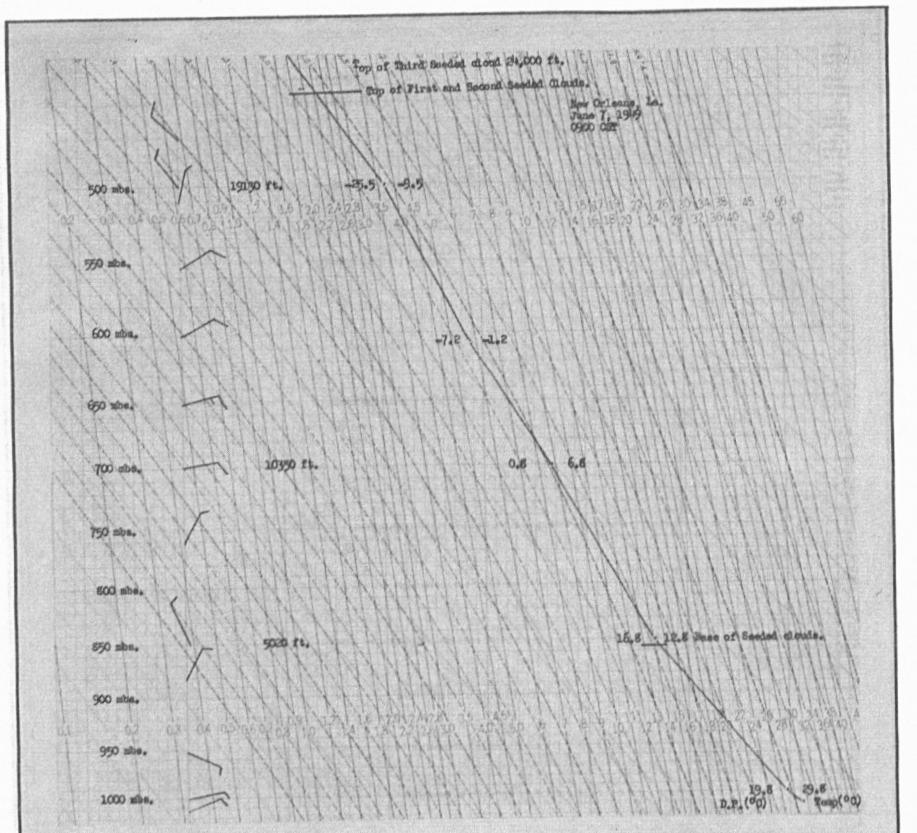

New Orleans, La.
May 23, 1949
0900 CST
500 mb
19320 ft.
-19.8 -14.5
-22.2 -11.2
-24.8 -9.5
Top of cloud 1st seeding: 18500 ft.
" " " 2nd " " : 18000 ft.
" " " 3rd " " : 18000 ft.
" " " 4th " " : 18000 ft.
" " " 5th " " : 16000 ft.
10500 ft.
-11.5 9.5
5130 ft.
Base of cloud during all seeding runs: 4500 ft.
-7.8 16.5
+3.5 16.2
+3.2 35.8
+21.0 26.0
+26.5 27.5
D.P. (°C)
Half-barb = 5 mph
Full-barb = 10 mph
New Orleans, La.
May 24, 1949
0900 CST
500 mb
19350 ft.
-15.5 -19.5
Top of cloud 1st seeding: 16500 ft.
" " " 2nd & 3rd seeding: 18000 ft.
10530 ft.
-10.5 8.5
5260 ft
+13.9 17.2
Base of cloud on all 3 seeding runs: 3000 ft.
+20.2 22.8
+22.2 26.5
+23.2 28.2
D.P. (°C) Temp. (°C)
Half-barb = 5 mph
Full-barb = 10 mph
1050 mb

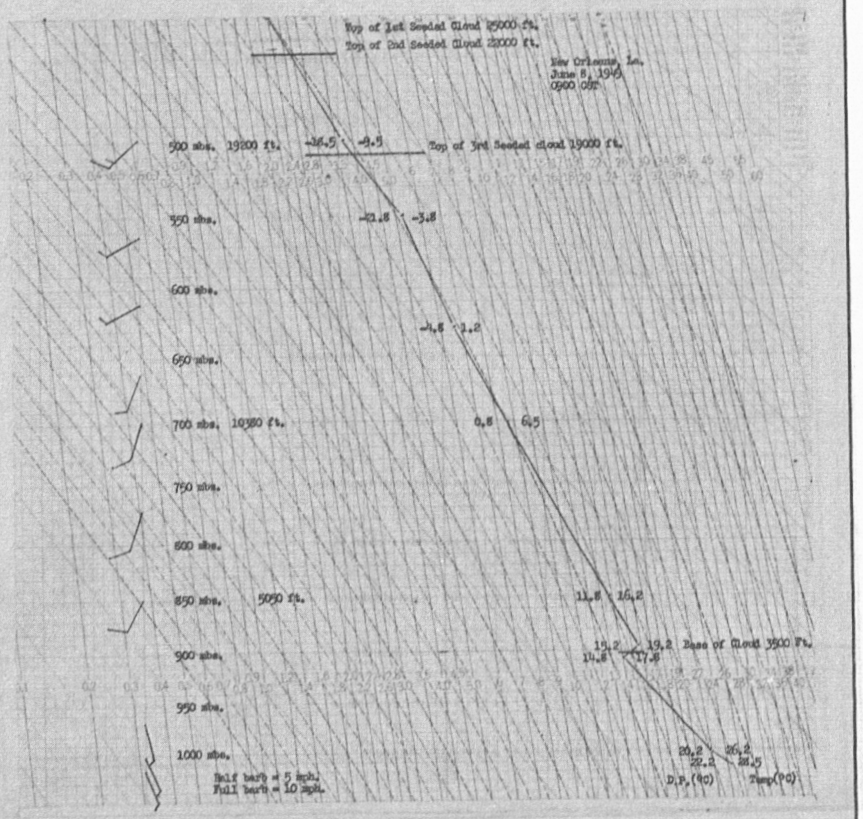

New Orleans, La.
May 27, 1949
0900 CST
500 mb. 19280 ft.
-19.2 -9.8
-26.8 -9.2
-14.8 -8.5
Top of cloud 1st seeding: 19000 ft.
" " " 2nd " : 17500 ft.
" " " 3rd " : 25000 ft.
" " " 4th " : 25000 ft.
" " " 5th " : 25000 ft.
" " " 6th " : 19000 ft.
550
600
-11.5 -1.5
650
700 10430 ft.
0.2 5.8
750
800
850 5120 ft.
Base of cloud on all 6 seeding runs- 5500 ft.
11.8 15.2
900
15.2 17.8
950
1000
29.2 26.8
20.8 28.2
D.P.(°C) Temp.(°C)
Half-barb = 5 mph
Full-barb = 10 mph
1050 mb

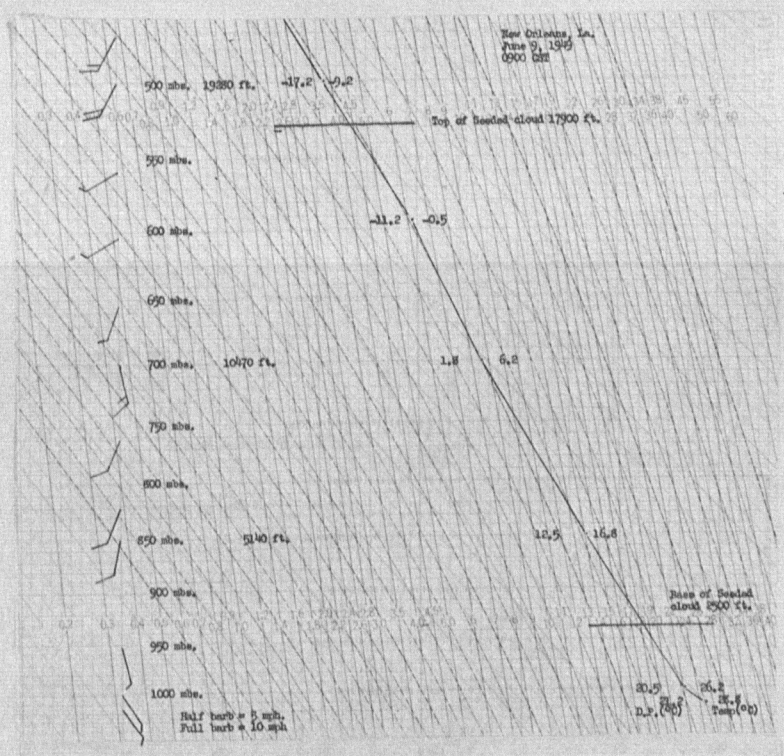

New Orleans, La.
June 1, 1949
0900 CST
500 mbs. 19260 ft. -23.8 -7.2
Top of Fourth Seeded Cloud
550 mbs.
Top of Third Seeded Cloud
Top of First Seeded Cloud
600 mbs. -18.5 -3.2
650 mbs.
700 mbs. 10420 ft. -12.2 9.8
750 mbs.
800 mbs. 10.2 16.2
850 mbs. 5030 ft. 10.2 18.8
Base of Seeded Clouds.
900 mbs.
19.2 23.8
19.2 22.5
950 mbs.
1000 mbs.
21.2 25.8
D.P.(°C) Temp.(°C)

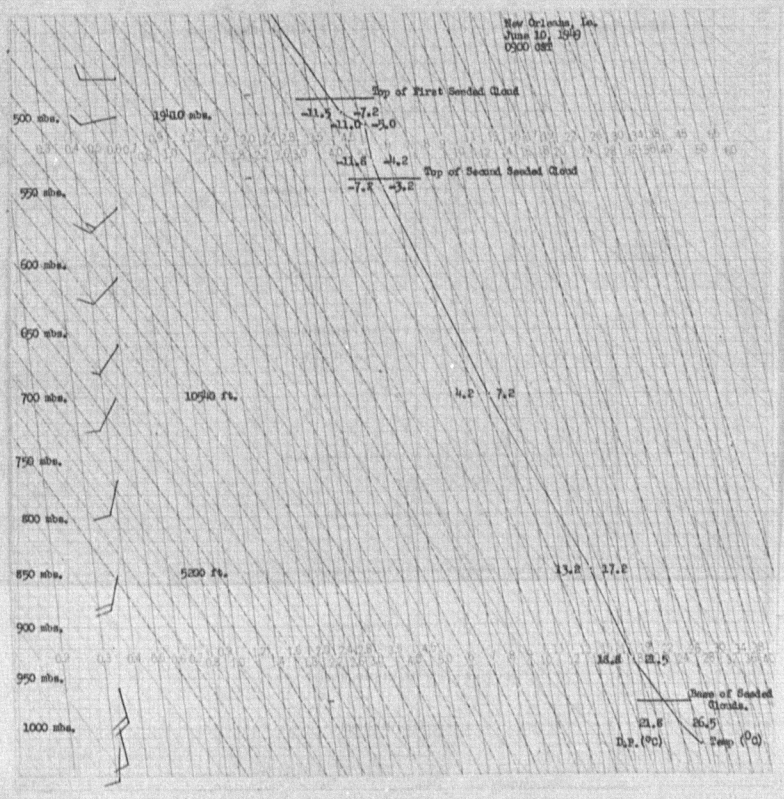

New Orleans, La.
June 5, 1969
0900 CST
500 mbs.
19240 ft.
-21.4
-8.2
Top of Sixth Seeded Cloud
Top of Fifth Seeded Cloud
550 mbs.
-20.8
-2.5
Top of Second Seeded Cloud
Top of First Seeded Cloud
Top of Third Seeded Cloud
600 mbs.
-9.8
0.5
Top of Fourth Seeded Cloud
-16.5
2.2
650 mbs.
-3.2
4.2
700 mbs.
10420 ft.
0.8
6.2
750 mbs.
Mag
9.2
-4.5
10.5
7.0
13.0
800 mbs.
Base of Seeded Clouds.
850 mbs.
5100 ft.
11.5
16.2
900 mbs.
950 mbs.
1000 mbs.
19.0
27.0
D.P.(°C)
Temp(°C)

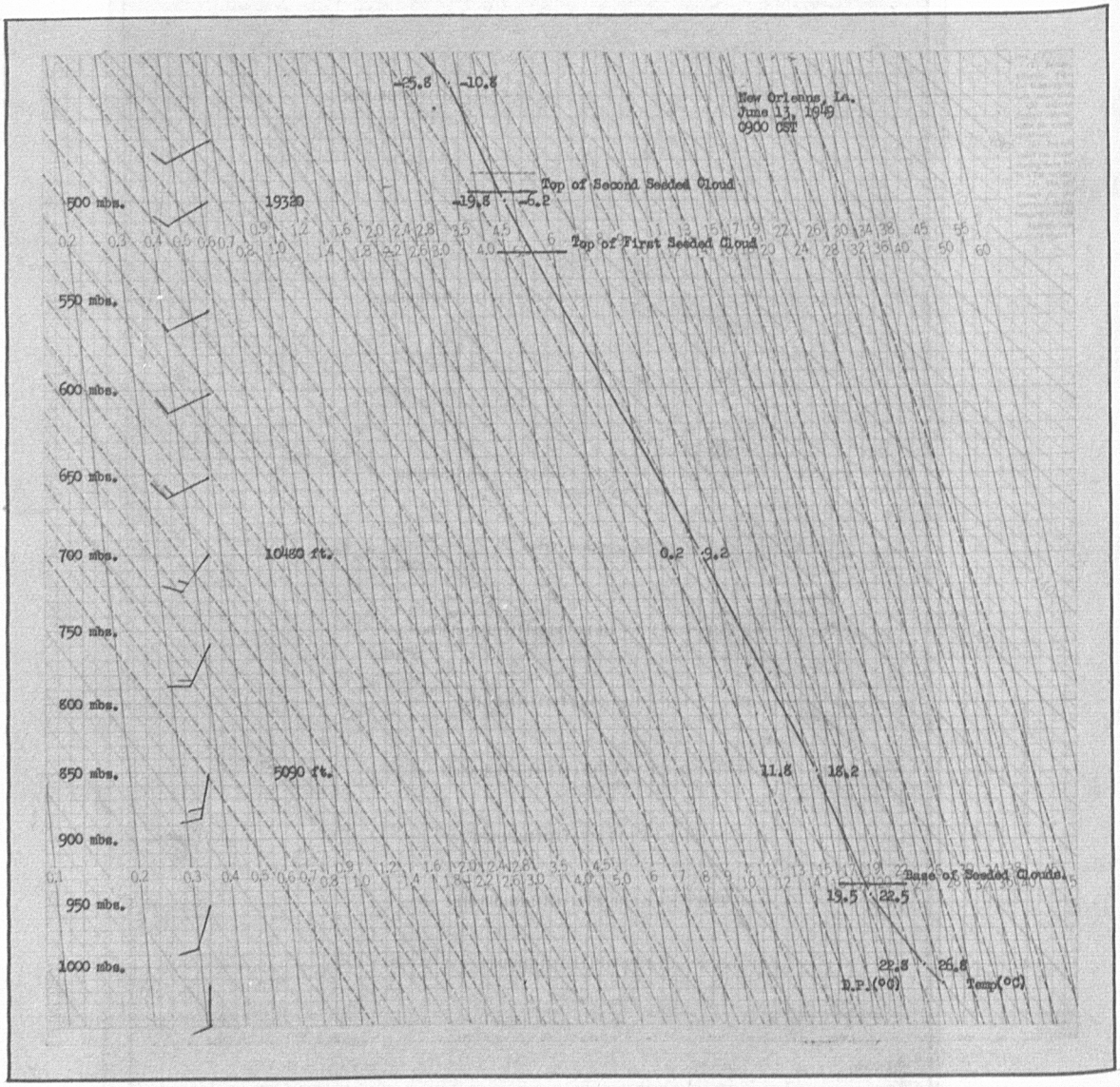

-20.8
-17.8
New Orleans, La.
June 5, 1969
0900 CST
Top of First Seeded Cloud
500 mbs.
19030 ft.
-21.5
-6.2
Top of Second Seeded Cloud
Top of Third Seeded Cloud
550 mbs.
600 mbs.
650 mbs.
700 mbs.
10380 ft.
0.2
7.2
750 mbs.
800 mbs.
850 mbs.
5050 ft.
12.5
16.5
Base of Seeded Clouds.
900 mbs.
950 mbs.
1000 mbs.
18.5
27.5
D.P.(°C)
Temp(°C)


Top of Third Seeded cloud 24,000 ft.
Top of First and Second Seeded Clouds.
New Orleans, La.
June 7, 1949
0900 CST
500 mbs.
19130 ft.
-25.5 -9.5
550 mbs.
600 mbs.
-7.2 -1.2
650 mbs.
700 mbs.
10350 ft.
0.8 6.8
750 mbs.
800 mbs.
850 mbs.
5020 ft.
16.8 12.8 Base of Seeded clouds.
900 mbs.
950 mbs.
1000 mbs.
19.8 29.8
D.P.(°C) Temp(°C)


Top of 1st Seeded Cloud 25000 ft.
Top of 2nd Seeded Cloud 23000 ft.
New Orleans, La.
June 8, 1949
0900 CST
500 mbs. 19200 ft.
-26.5 -9.5
Top of 3rd Seeded cloud 19000 ft.
550 mbs.
-12.8 -3.8
600 mbs.
-4.8 1.2
650 mbs.
700 mbs. 10380 ft.
0.8 6.5
750 mbs.
800 mbs.
850 mbs. 5050 ft.
14.8 16.2
900 mbs.
19.2 19.2 Base of Cloud 3500 ft.
14.8 17.8
950 mbs.
1000 mbs.
20.2 26.2
22.2 28.5
D.P.(°C) Temp(°C)
Half barb = 5 mph.
Full barb = 10 mph.


New Orleans, La.
June 9, 1949
0900 CST
500 mbs.
19380 ft.
-17.2
-9.2
Top of Seeded cloud 17900 ft.
550 mbs.
600 mbs.
-11.2
-0.5
650 mbs.
700 mbs.
10470 ft.
1.8
6.2
750 mbs.
800 mbs.
850 mbs.
5140 ft.
12.9
16.8
900 mbs.
Base of Seeded cloud 2500 ft.
950 mbs.
1000 mbs.
20.9
26.2
21.2
D.P.(°C)
24.8
Temp.(°C)
Half barb = 5 mph.
Full barb = 10 mph


New Orleans, La.
June 10, 1949
0900 CST
Top of First Seeded Cloud
500 mbs.
19410 mbs.
-11.2
-7.2
-11.0
-3.0
-11.6
-4.2
Top of Second Seeded Cloud
-7.8
-3.2
550 mbs.
600 mbs.
650 mbs.
700 mbs.
10540 ft.
4.2
7.2
750 mbs.
800 mbs.
850 mbs.
5200 ft.
13.2
17.2
900 mbs.
16.6
21.5
950 mbs.
Base of Seeded Clouds.
1000 mbs.
21.8
26.5
D.P.(°C)
Temp (°C)


New Orleans, La.
June 13, 1949
0900 CST
-25.8 -10.8
Top of Second Seeded Cloud
-19.8 -6.2
Top of First Seeded Cloud
500 mbs.
19320
550 mbs.
600 mbs.
650 mbs.
700 mbs.
10480 ft.
0.2 9.2
750 mbs.
800 mbs.
850 mbs.
5090 ft.
11.8 18.2
900 mbs.
Base of Seeded Clouds
19.5 22.5
950 mbs.
1000 mbs.
22.8 26.8
D.P.(°C)
Temp(°C)